UNIVERSITY OF EDINBURGH.

A THESIS

ENTITLED

STUDIES ON THE BIOLOGY AND CONTROL OF THE HEATHER-BEETLE, LOCHMAEA SUTURALIS THOS.

SUBMITTED FOR

THE DEGREE OF

DOCTOR OF PHILOSOPHY

by

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Contents.

(With Plates 1 to 4 and 10 Text-figures).

INTRODUCTION.

In July 1937 I was appointed assistant to Dr. A.E. Cameron, head of the Department of Entomology, Edinburgh University, in order to investigate the life history of the heather-beetle, Lochmaea suturalis, about the activities of which considerable anxiety had been expressed in recent years by the owners of grouse moors. The cost of the investigation, which proceeded until September 1939, was borne in its entirety by the British Field Sports Society, and due appreciation is felt for the continued interest of the Secretary of the Society, Mr. J.W. Fitzwilliam, in the progress of the work.

The investigation has been primarily a study of the biology of the beetle. Since studies in the morphology of L. suturalis have been adequately carried out by previous authors, only brief general descriptions of the various life history stages are included in this account.

Thanks are due to my supervisors, Dr. Cameron and Mr. J.W. McHardy, for the encouragement, advice and criticism freely offered. The translation from the Dutch of Betrem's monograph was undertaken by Dr. Cameron and the photography was supervised by Mr. McHardy. Tribute must also be paid to those moor owners and others whose co-operation contributed materially to the progress of our studies.

HISTORICAL /

HISTORICAL.

The earliest account of the occurrence of heather-beetle is by Cornelius (1858) when he recorded that in 1853 vast swarms invaded houses, gardens and roadways near Elberfeld in Germany, but the insects were not observed feeding and the food plant was not noted. They were recorded again by Cornelius (1862) who found them in great numbers in 1861, in sparsely wooded areas where the food plant, heather, was said to have been consumed over a wide area; their ravages continued into 1862.

Lochmaea suturalis was first described and named by Thomson (1866) and in the account they are stated as being "not rare on *Salix repens* and other species of willow."

Canon Fowler (1891) recorded that it is found "on heather, by no means uncommon and very widely distributed - it also occurs on birches and willows."

In 1893 Weise reported in his description of the species that it occurs "on marsh plants and also on birches and willows growing in marshes", but in a memorandum stated, "*L. suturalis* lives chiefly on *Calluna vulgaris* around the edges of fir plantations."

In Great Britain its occurrence on heather was first brought to the notice of Grimshaw in 1897 and he published a short account of it in 1898. Later, in 1909 he undertook an investigation of its life history at the request of the Grouse Disease Inquiry Committee. At that time there was increasing recognition of an association between the beetle and so-called "frosted", "burnt" or "scorched" heather, and there were numerous reports of the occurrence of heather affected in this way and of the beetle itself. The discoveries /

discoveries made during this investigation were published in 1911, and a more complete account was presented in 1913.

Betrem (1929) recorded that the beetle had been injurious for sixty years in the Rhineland and north Holland, and that damage to heather occurred abundantly at Apeldoorn. In Holland, damage was first observed in 1919-23, became acute in 1926 and finally in 1927 was responsible for drastic losses to beekeepers. The biology and morphology of the beetle in all stages were described by Betrem, and a comparison of the adult was drawn with that of Lochmaea capreae, a closely related species. The monophagous habit of L. suturalis was stressed.

In the same year Prell (1929) described the life history, compared it with that of L. capreae, contrasted it with that of Galerucella lineola, and differentiated morphologically the adults of the three related species of Lochmaea, namely suturalis, capreae and crataegi. Prell likewise recognised that the beetle was monophagous.

Corax (1930) reported the occurrence of severe damage to heather in North German, particularly in the Luneburger Heide.

In this country and particularly in Scotland, attention was recently again drawn to severe beetle damage to heather. In 1937 Cameron published an account of the life history of the heather-beetle including a brief general description of the various stages, and suggested measures of control. A short general account of the beetle was also published by Morison in 1938.

That /

That the beetle has been responsible for extensive injury to heather in recent years was clearly shown by the correspondence published by Parker (1936), and more especially in communications received during the course of the present investigation. Morison (1938) reported that in the north and north-east of Scotland injury to heather was widespread and most severe in 1935. In Scotland, the west and south-west areas appear to have suffered most from the depredations of the beetle.

NATURE OF INJURY TO HOST PLANT.

LOCATION OF INFESTED AREAS.

In July and August the leaves and stems of heather attacked by beetle larvae become fox-red, and on careful examination are found to have been chewed and frequently partly stripped, particularly the apical portions of young shoots. (Plate III, fig. 2). The whole, or only one or more branches of an individual plant may be affected; in the latter case recovery is more likely to occur. The following year, heather which has been killed becomes grey in colour and the leaves drop off. Sometimes when only part of a plant has been attacked, that part only is affected in this manner, and the remainder of the plant remains alive and green.

In our experience, heather of any age is liable to attack; but whereas young vigorous heather up to eight or ten years is seldom killed, old heather approaching twenty years or more often succumbs to the attack of the beetle, and on moors where severe damage to heather had occurred, most of the heather was found to be /

be very old. (Plate III, Fig. 1.). Very young heather may be attacked but rarely does the attack result in permanent damage. This observation is not in agreement with the opinion of Morison (1938) that plants 18 ins. tall are but little affected by the insect, and serve to support only a few individuals, and that the largest number of beetles are reared on plants from 2 to 14 ins. tall. Morison remarked further that the smaller the plant, the more severe is the damage.

Damage may occur uniformly over an expanse of heather, or it may be confined to small patches here and there, and is very often most severe on the margins of small plots and along the edges of pathways and drains. No satisfactory explanation of this last phenomenon has been found. When, however, the distribution is patchy the affected areas are noticeably situated in the wettest spots.

Beetles were found to be present on all kinds of heather moorland but were much more abundant on wet boggy ground whether the situation was inland or coastal, irrespective of altitude or exposure. The investigation confirmed the opinion expressed by Grimshaw (1913) and Cameron (1937) that flat wet moorlands are generally those which suffer most from beetle attack. Well drained slopes are rarely affected. When attack by the beetle does occur on sloping ground it is found that the soil is shallow and is kept moist by seepage water draining from the ground above.

When a moor includes large tracts of marshy ground and the beetles become numerous, there is always the chance that they may invade /

invade adjacent dry areas in spring, and feed on the heather there. The consequent destruction of the buds may result in a decided scarcity of blossom, but the brown or red coloration of the injured heather does not materialise, since this symptom of damage is produced only by the larvae. Scarcity of blossom is especially noticeable in late summer, but is also apparent by the absence of withered flowers throughout the winter following a severe attack, whereas the fox-red appearance of the heather due to larval attack is of short duration. In Holland, instances of local damage due to temporary visitations of swarming beetles are referred to by Betrem (1929).

OUTLINE OF INVESTIGATION.

The life history of the heather-beetle was studied with a view to determining the factors which encourage both the increase and decrease of the heather-beetle population, and also to investigate practical measures of controlling the beetles' activities. Although the work was begun when the infestation of the beetle was already on the wane, there was nevertheless abundant opportunity to study the type of habitat best suited to this pest.

The first part of the report deals with the life history of the heather-beetle, the interpretation of data relating to field collections throughout the year and a discussion of the various stages of the beetle, egg, larva, pupa and adult, particularly in relation /

relation to environment. Laboratory experiments which were chiefly designed to confirm conclusions derived from field observations are described in each section. There then follow accounts of the natural enemies of the heather-beetle, the influence of climatic factors on the beetle population and the control of the beetle by insecticides, heather burning and drainage. There is also included a short account of the heather-weevil and Vapourer moth the work and various stages of which are sometimes confused with those of the heather-beetle by game-keepers. Lastly the occurrence of injury to heather by factors other than insect pests is briefly reviewed.

STUDY OF LIFE-CYCLE OF L. SUTURALIS IN THE FIELD.

The life cycle of the heather-beetle may be summarised as follows. The adult beetles overwinter and eggs are not laid until spring, the larvae feed during the summer and the new generation of adults emerge from the pupae in autumn. The eggs, pupae and hibernating adults were found by searching among sphagnum and soil debris and the active adults and larvae were collected by means of a sweep-net. As a guide to the commencement of oviposition, female beetles were dissected at regular intervals to determine the state of development of the ovaries. Collections of adults and larvae were made throughout 1937 and 1938 and the data are recorded in Tables I and II. In 1938 a uniform method of sampling was adopted, each sample consisting of all individuals, larvae and adults, /

adults, captured by making 100 strokes of the net. It is considered by Carpenter and Ford (1936) that, in estimating changes in the density of an insect population throughout the year, samples of 100 sweeps are reliable.

Inspection of Tables I and II shows the time of year during which the three larval stages and the adult of L. suturalis are to be found, and similar data are given with regard to Coccinella hieroglyphica and Strophosomus lateralis. The information obtained with regard to the last two insects is discussed on pages 49 and 81 and that about the former on pages 15 and 20.

THE EGG.

The eggs were first described by Grimshaw in 1913. They possess a pitted chorion and are usually spherical or slightly oval in shape, but many are quite irregular. They vary in size but the average mean diameter is 0.85 mm. The colour which is at first pale yellow and very shiny, darkens to orange in a few days and, just before the emergence of the larva, turns dark brown. Eggs which have hatched are pale yellow but dull, and each possesses an irregular aperture through which the larva emerged.

The eggs are found in abundance, principally on the moss, Sphagnum acutifolium (Plate I, Fig. 4), usually near or on the crown of the plant, singly or in groups of two or three and occasionally ten or more. Several groups may occur within a radius of a few inches. Eggs have also been found on another moss, Sphagnum cymbifolium, which predominates in some areas, but /

Table I.

Numbers of various instars of L. suturalis, C. hieroglyphica and S. lateralis captured in various localities during the latter half of 1937, by sweeping heather with an insect net. +

Date 1937	L. suturalis Adults	Larval Instars 1	2	3	Total	C. hieroglyphica Adults	C. hieroglyphica Larvae	S. lateralis Adults
June 7	*	–	–	–	–	–	–	–
28	*	35	8	–	43	–	–	–
July 12	*	10	33	3	46	3	5	–
15	15	13	58	17	88	–	15	–
19	5	2	24	32	58	–	1	–
22	8	4	19	69	92	5	5	–
Aug. 2	2	2	10	80	92	10	–	–
4	2	2	15	96	113	11	1	–
10	1	1	5	39	45	7	–	–
20	1	–	3	15	18	20	–	–
23	5	–	–	6	6	46	1	61
26	4	–	–	3	3	40	–	52
Sept. 2	114	–	–	6	6	3	1	–
6	14	–	–	–	–	9	–	41
10	121	–	–	–	–	16	–	–
13	19	–	–	–	–	4	–	–
18	696	–	–	–	–	11	–	240
Oct. 12	67	–	–	–	–	5	–	9
14	6	–	–	–	–	3	–	7
20	54	–	–	–	–	1	–	–
Nov. 3	7	–	–	–	–	–	–	2
5	28	–	–	–	–	–	–	–
Dec. 1	6	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–

+ As the numbers of net strokes per sample were not the same for each, the samples are not strictly comparable.

* The adults were abundant on these dates.

Table II.

Numbers of various instars of L. suturalis, C. hieroglyphica and S. lateralis captured in various localities in 1938 by sweeping heather with an insect net.+

Date 1938	Air Temp. in °F.	L. suturalis Adults	Larval Instars 1	2	3	Total	C. hieroglyphica Adults	C. hieroglyphica Larvae	S. lateralis Adults
Feb.18	-	-	-	-	-	-	-	-	-
March 4	47	-	-	-	-	-	-	-	-
11	55	67	-	-	-	-	1	-	1
13	58	91	-	-	-	-	2	-	19
16	57	86	-	-	-	-	-	-	-
22	50	70	-	-	-	-	1	-	-
25	44	-	-	-	-	-	-	-	-
29	48	6	-	-	-	-	-	-	-
April 1	52	58	-	-	-	-	-	-	4
4	47	19	-	-	-	-	1	-	3
7	52	77	-	-	-	-	-	-	-
28	51	52	-	-	-	-	-	-	-
30	47	10	-	-	-	-	-	-	-
May 3	49	32	-	-	-	-	-	-	3
5	51	65	-	-	-	-	-	-	-
6	57	75	-	-	-	-	-	-	-
7	49	9	-	-	-	-	-	-	-
8	53	35	-	-	-	-	-	-	-
13	59	78	-	-	-	-	-	-	-
June 8	-	46	-	-	-	-	-	-	-
10	-	46	-	-	-	-	-	-	-
14	-	18	-	-	-	-	-	-	-
15	-	30	-	-	-	-	-	-	4
16	-	45	-	-	-	-	-	-	4
20	-	29	-	-	-	-	-	-	4
July 1	-	19	106	4	-	110	-	-	-
12	-	12	98	3	-	101	-	-	5
19	-	12	66	45	2	113	1	-	-
22	-	8	190	347	14	551	-	-	-
23	-	23	202	340	17	559	-	-	-
Aug. 1	-	6	65	134	343	542	2	8	-
3	-	-	24	132	316	472	-	8	-
8	-	18	22	158	288	468	-	-	-
11	-	10	12	116	316	444	-	-	-
17	-	-	-	66	208	274	-	-	-
20	-	2	-	12	136	148	-	-	-
22	-	-	-	-	106	106	-	-	-
26	-	-	-	-	61	61	3	-	-
Sept. 2	-	2	-	-	-	-	30	-	-
5	-	-	-	-	-	-	8	-	-
8	-	1	-	-	-	-	4	-	-
16	-	8	-	-	-	-	22	-	-
26	-	60	-	-	-	-	12	-	-
Oct. 15	56	69	-	-	-	-	3	-	-
20	54	74	-	-	-	-	2	-	-
24	55	41	-	-	-	-	3	-	-
Nov. 8	49	15	-	-	-	-	-	-	-
20	49	9	-	-	-	-	-	-	-
28	32	-	-	-	-	-	-	-	-
Dec. 10	32	-	-	-	-	-	-	-	-

+samples were each obtained by 100 strokes of the net, and are therefore comparable.

but this moss is not so suitable as the former owing to its lesser capacity for retaining moisture; and eggs are occasionally laid on the soil or even on the stems of heather near the base but not in large numbers. The eggs are expressed by the female along with the excrement, a portion of which almost invariably adheres to the chorion.

From mid-April until early June eggs were found to be scarce and until late June there were few larvae so it can be said that out of doors the eggs hatch three or four weeks after oviposition. Indoors the average period of incubation was determined at the following constant temperatures, 17°C., 20°C., 25°C., and 30°C. and the results are tabulated in Table III. The procedure was to remove daily eggs laid by beetles kept in captivity, place them on small pieces of wet sphagnum and enclose them in tubes the corks of which were each bored with a narrow hole plugged with cotton wool. The tubes were opened once a day for examination and the sphagnum remoistened if necessary; this secured adequate ventilation and an atmosphere saturated with moisture. Indeed, the eggs were in actual contact with the film of water surrounding the moss.

Table III. /

Table III.

Incubation period of eggs of L. suturalis.

Temperature	No. of eggs.	Average period in days.
17.5°C	1965	18.56
20.0°C.	259	13.20
25.0°C.	170	9.10
30.0°C.	147	-

Reference to Table III shows that a temperature of 30°C (86°F) is lethal to the eggs. At a constant temperature of 17.5°C (63.5°F) the period of incubation is 18 or 19 days. This is a rather shorter period than that occupied under natural conditions where the eggs are exposed to fluctuating temperatures.

Influence of relative humidity on incubation.

It was observed in the field that the eggs were invariably laid in moist situations, and that on removal to a dry environment they dried and shrivelled rapidly. It seemed, therefore, that a high degree of humidity was necessary for the successful development of the eggs and an experiment was made to determine the relative humidity best suited to their successful incubation.

In the experiment (Table IV), aqueous dilutions of sulphuric acid were employed to give the requisite humidities. The eggs were kept in sealed jars each of which contained a sufficient quantity of the appropriate dilution of acid and were incubated at 20°C. The eggs were placed on small pieces of sphagnum supported on glass platforms near the top of the jars except for one jar in which they were immersed in half an inch of water. The small quantity /

quantity of water held by the moss raised the humidity in each jar a little above that stated in the table.

From Table IV the optimum relative humidity is seen to be about 98% and the results from this experiment are represented in text-figure 1. It is interesting to find that some eggs succeeded in hatching even when submerged during development. That a high degree of relative humidity is necessary for the successful development of the eggs explains why attacks of the heather-beetle are most severe on boggy moorlands with an abundance of sphagnum. By its retention of water the moss protects the eggs from being injured by desiccation during periods of dry weather. The effect of long periods of spring drought is discussed on page 57.

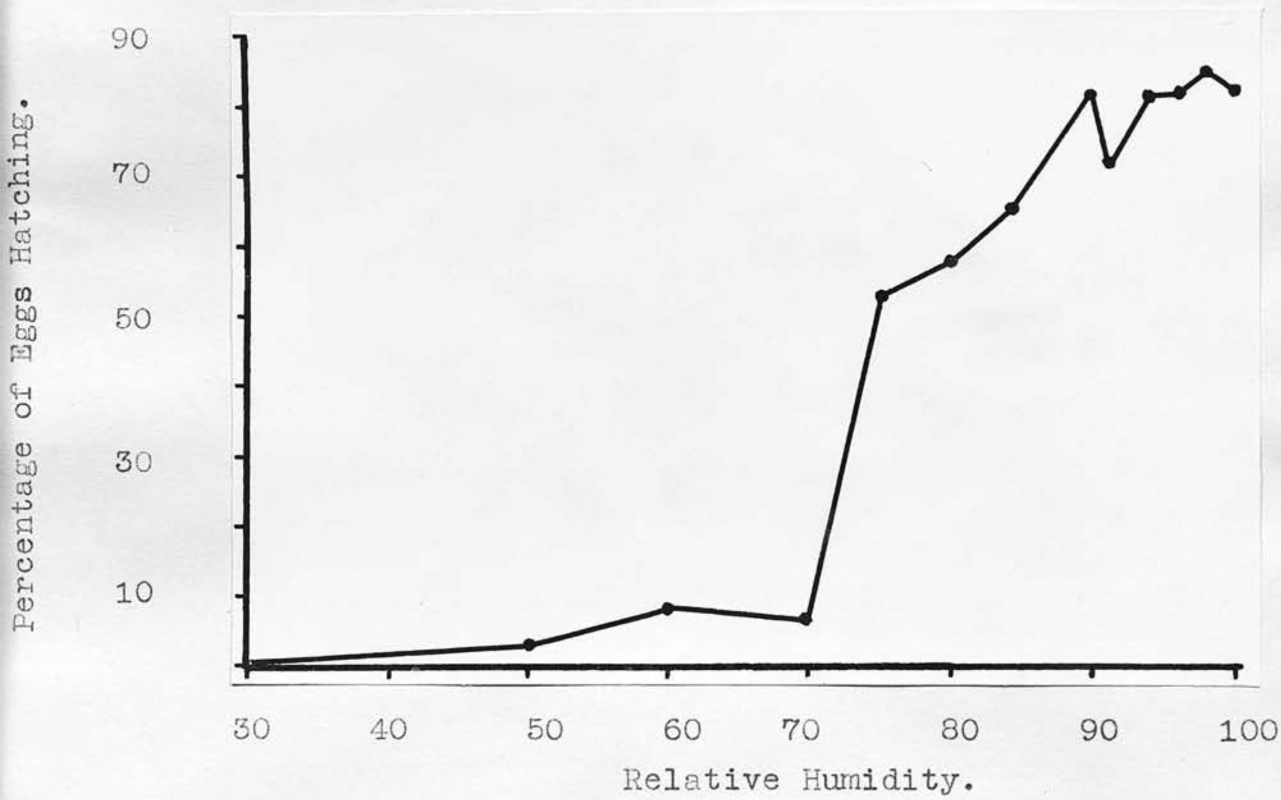
Table IV.

Percentages of eggs of L. suturalis successfully incubated at 20°C and various relative humidities.

Relative humidity	No. of eggs.	Percent. of hatched eggs.	Relative humidity	No. of eggs	Percent. of hatched eggs.
(submerged in water)	15	40.0	85%	96	66.7
100%	86	80.2	80%	95	56.8
100%	100	82.0	75%	99	52.6
98%	92	83.7	70%	99	5.1
96%	104	80.8	60%	106	7.5
94%	95	80.0	50%	98	2.1
92%	98	70.4	30%	100	0.0
90%	95	81.1	-	-	-

Effect of frost on incubation.

As egg-laying occurs in early summer, the eggs would not normally be subjected to frost out of doors. Nevertheless it was considered /



Text-figure. 1. Percentages of Eggs of L. suturalis hatching when incubated at 20°C. and various Relative Humidities.

considered a matter of interest to investigate the resistance of the egg to low temperature. In the laboratory, batches of eggs of different ages were exposed to 0°C. for a period of 16 hours and other batches to 0°C. for two periods of 16 hours each, separated by an interval of 8 hours; a third set, maintained at 20°C., was used as a control. The eggs were kept on wet sphagnum in corked glass vials and the first two sets of batches were incubated at a constant temperature of 20°C., before and after exposure to 0°C., whilst the control batch was kept continuously at 20°C (Table V).

Table V.

<u>Effect on hatching of exposure to temperatures of 0°C. to -1°C. of incubating eggs of</u> L. suturalis.

Approx. age of eggs in days.	(a) Exposed to 0°C. for 16 hours		(b) Exposed to 0°C. for two periods of 16 hours, separated by an 8 hour period.	
	No. of eggs	Per cent. of hatched eggs	No. of eggs	Per cent. of hatched eggs.
1	48	88	48	88
2	49	84	52	81
3	40	73	51	65
4	51	82	55	75
7	50	94	51	86
8	46	76	53	75
9	47	83	47	79
11	60	87	53	83
12	+ 57	56	52	73
13	47	94	53	72
14	52	96	49	63

(c) /

(c) Exposed to 20°C. continuously.

No. of eggs	Per cent. of hatched eggs.
44	84
43	77
+42	62
44	86
45	80
+41	71

\+ Many of the eggs in the tubes were killed by fungi. Therefore. the percentages of hatched eggs in these tubes were ignored in considering the results.

It was calculated from Table V that the average percentages of hatched eggs were 86% in (a) 76% in (b) and 81% in (c). As there is no significant difference between the averages it must be concluded that exposure to 0°C. at any stage of their development does not appreciably affect the hatching of the eggs.

THE LARVA.

The three larval instars differ but little from one another in appearance or structure. The stages can be separated quite readily by the size of the head capsules. Full grown larvae (Plate I, fig. 3.) are about 12 mm. in length and at rest assume a slightly curved posture. After each moult, the sclerites of the segments are but slightly separated and, as these are dark in colour, the larvae appear grey or greyish-white when viewed dorsally. As the larvae grow, the sclerites become further separated with the result that the inter-scleritic areas are more conspicuous and give the integument a lighter appearance. The head is black. There are /

are three pairs of well developed thoracic limbs, and the rectum, which protrudes from the tenth and last abdominal segment, forms an anal sucker which is used as an adhesive organ in locomotion. The larvae escape by biting an irregular hole in the chorion of the egg, and find their way to the food plant which they do not leave until they are ready to pupate. They are not readily dislodged. Moulting generally takes place in the axil of a branch.

In order to determine the relative duration of the stadia, larvae were reared at room temperature, about 15.5°C. and at a constant temperature of 25°C. Small shoots of heather placed upright in glass vials were provided as food for the larvae. The results obtained from these rearing experiments are recorded in Table VI.

The development of the larvae at laboratory temperature (15.5°C.) occupied 24 days, (Table VI) which is a much shorter period than what occurs out of doors as is shown below. At 25°C. the period is reduced to 16 days and, like the eggs, the larvae do not develop successfully at 30°C.

In order to represent the duration of the larval stadia in the field, the data given in Tables I and II are expressed in graphical form in text-figures 2 and 3 which show respectively the numbers of larvae caught throughout the season in 1937 and 1938; in each collection the numbers of each larval instar were stated as a percentage of the whole. Text-figures 4 and 5 represent graphically the /

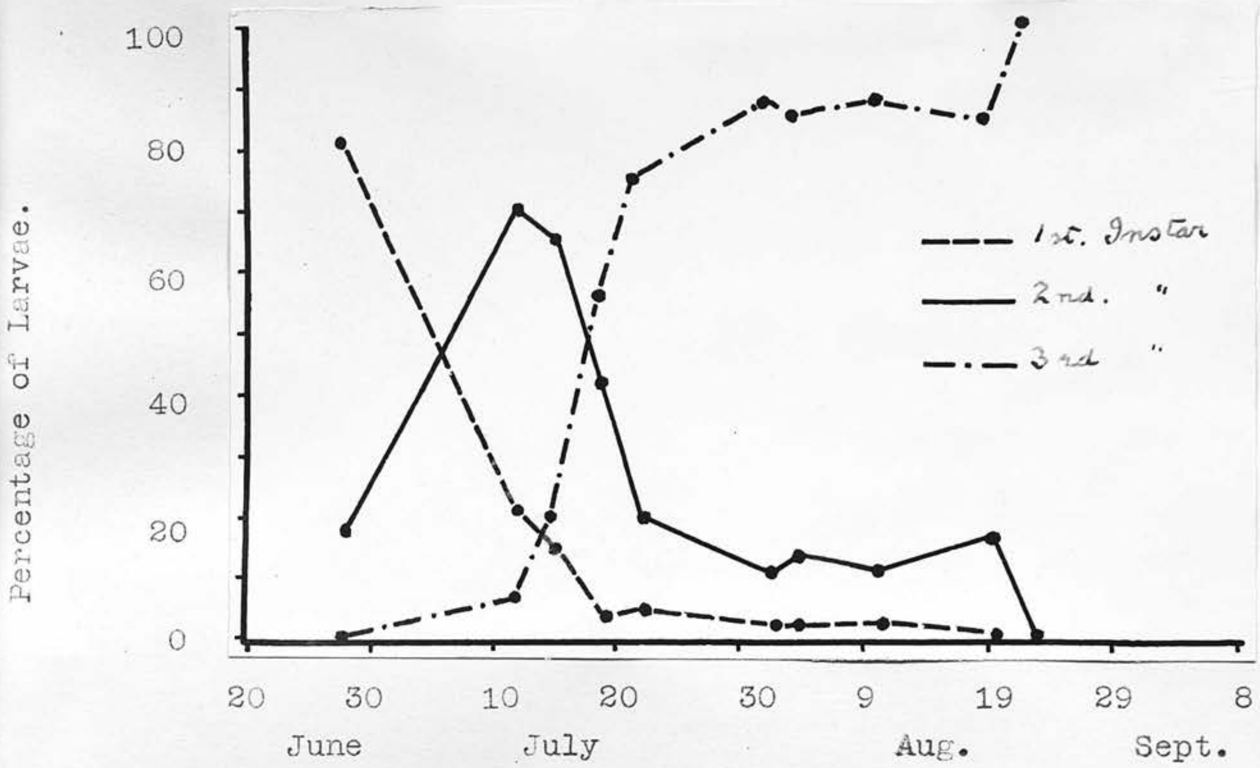
the actual numbers of the three larval instars, separately and collectively, caught in 1938 and detailed in Table II. It was not possible to make similar graphs of the data in Table I since in 1937 uniform sampling was not adopted.

Table VI.

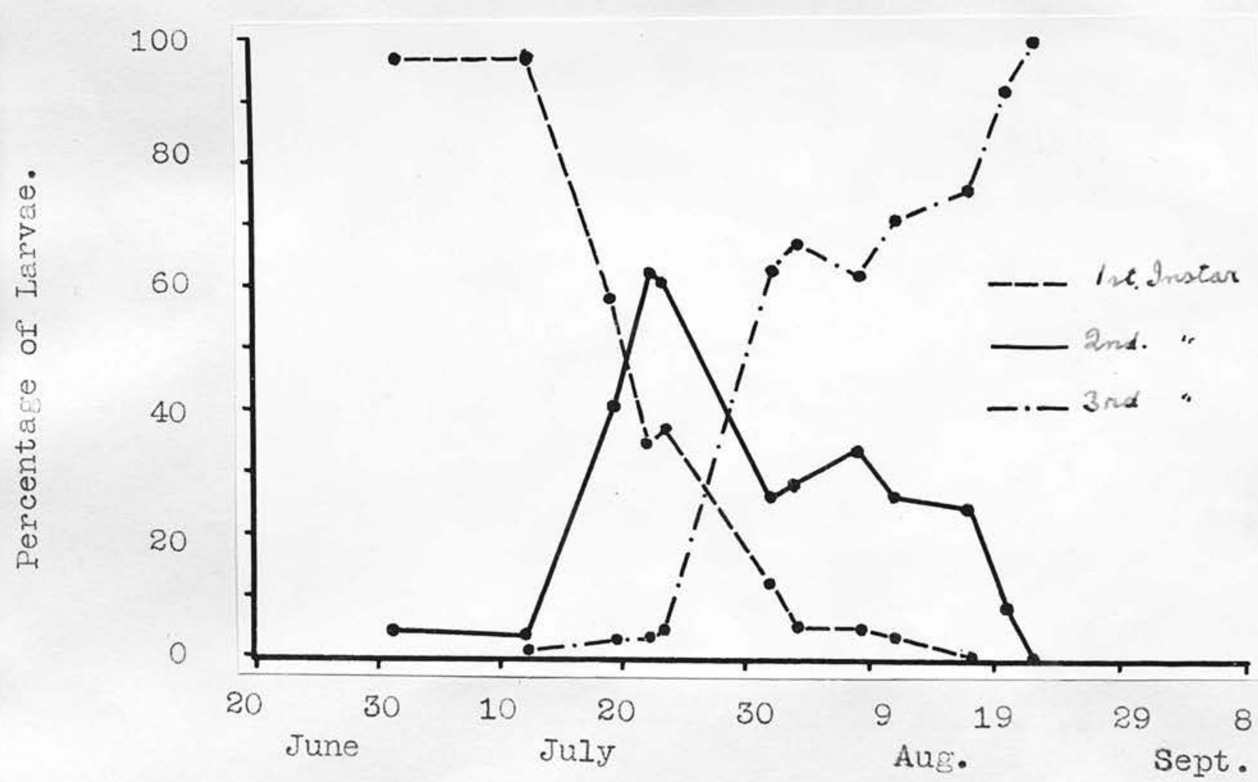
Duration of larval stadia of L. suturalis.

(a) Indoors at about 15.5°C. (60°F.)			(b) At a constant temperature of 25°C. (77°F.)		
Instar	No. Larvae	Average period in days	Instar	No. Larvae	Average period in days
1	163	9.1	1	65	5.61
2	151	7.36	2	48	5.10
3	161	7.6	3	26	5.00
all instars	-	24.06	all instars	-	15.71

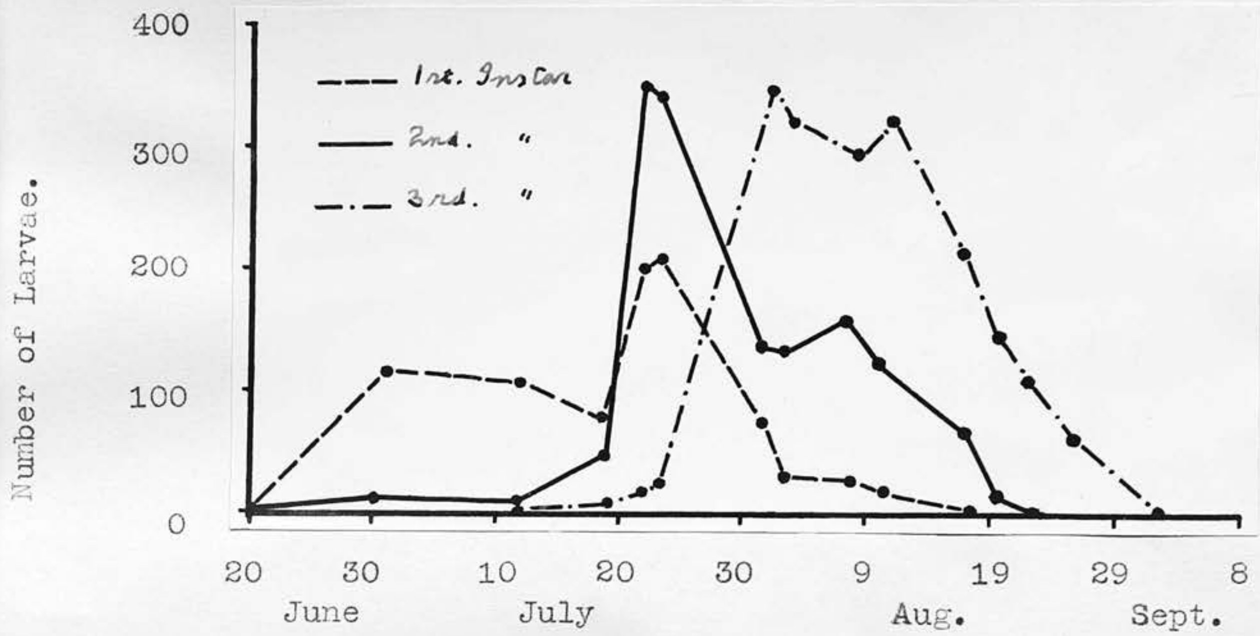
Inspection of text-figure 2 shows that the dates of greatest abundance of the first, second and third larval instars during 1937 were respectively about the 23rd of June for the first, the 13th July for the second and the 2nd August for the third and that the interval between these dates was about three weeks. From text-figures 3 and 4 it is seen that in 1938 the dates of greatest abundance of the three larval instars were respectively the 10th July, 25th July and 10th August and that the interval between these dates was about two weeks. Thus the season was later and the cycle shorter in 1938 than in 1937. That the larvae were in greatest numbers on the heather in 1938 during the last week of July is seen by consulting text-figure 5.



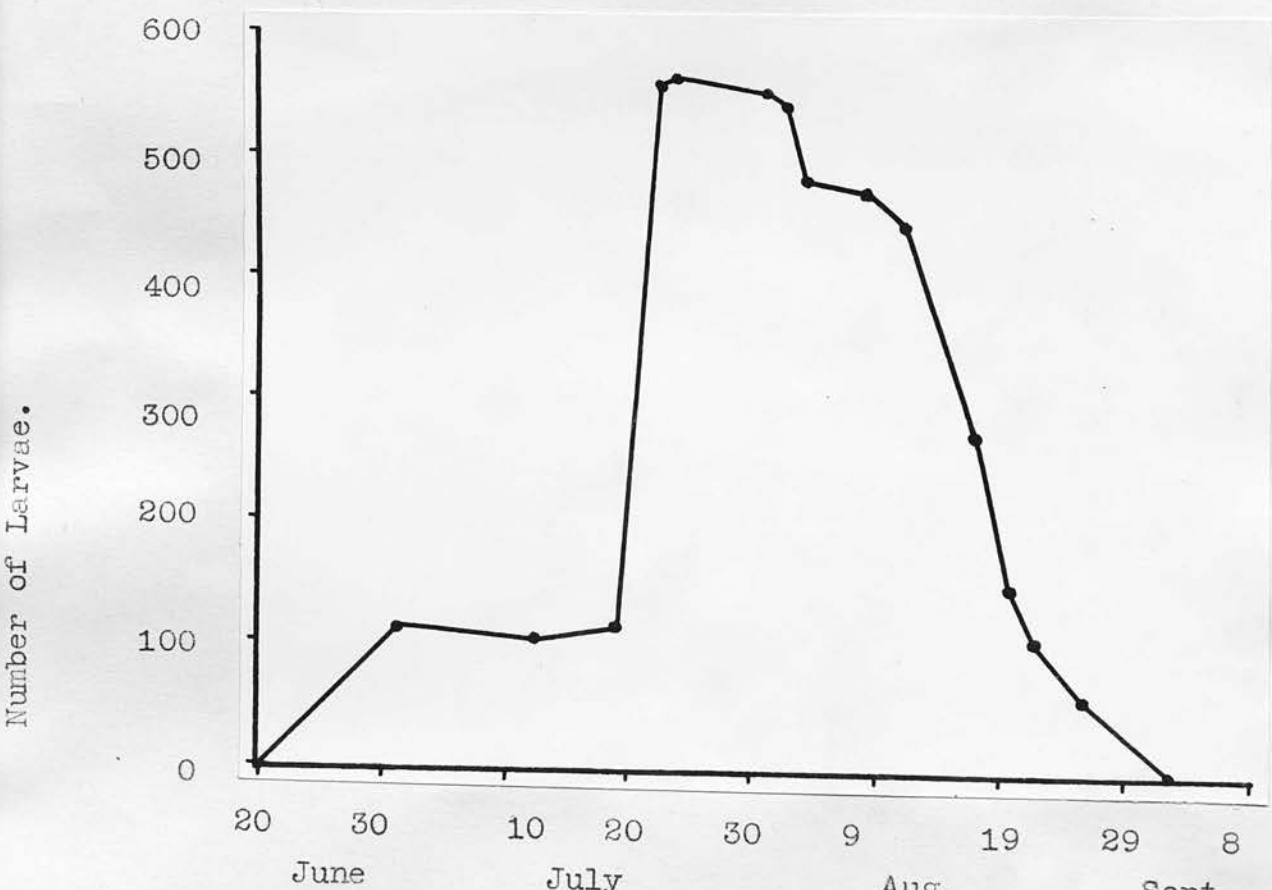
Text-figure 2. Percentages of Larval Instars of L. suturalis captured in various localities during 1937.



Text-figure 3. Percentages of Larval Instars of L. suturalis captured in various localities during 1938.



Text-figure 4. Numbers of 1st, 2nd and 3rd Instar Larvae of L. suturalis per 100 strokes of sweep-net captured in various localities during 1938.



Text-figure 5. Numbers of Larvae of all Instars of L. suturalis per 100 strokes of sweep-net captured in various localities during 1938.

THE PUPA.

The pupae (Plate I fig. 2) are found in situations similar to those in which the adults hibernate; the full grown larvae burrow just beneath the surface of the soil where they make protective earthen cells, or below the overlying cover of moss. The naked pupae are white to yellowish but darken as development proceeds and vary somewhat in size, but they are usually about 9 mm. long by 5 mm. in width. The exuviae which are very small are easily overlooked and the beetle has not been observed in the act of emerging from the pupal skin.

The duration of the combined prepupal and pupal stages at laboratory temperature (60°F.) was found to average 26.3 days. The duration of these same stages in the two sexes was found to be almost identical. Of 15 males the average duration was 26.3 days and of 15 females 25.4 days. At 25°C. the average duration of the prepupal stage of 21 individuals was found to be 5.76 days, and of 12 individuals, the pupal instar averaged 6.58 days. The two stages, therefore, are of approximately equal duration. In the field, pupae were found in increasing numbers from the beginning to the last week of August. They continued to be numerous until late September after which they became progressively fewer. The majority of the adult beetles emerged in late September. The appearance of large numbers of beetles four weeks after the majority of the larvae had pupated indicated /

indicated that this period was the approximate duration of the pupal instar in the field.

Influence of relative humidity on development.

It has been remarked that the larvae pupate in moist situations and the following experiment was designed in order to find the optimum relative humidity for the successful development of the pupae (Table VII). Newly formed pupae were placed in small glass tubes. These were enclosed in sealed jars in which the predetermined humidities were maintained by appropriate dilutions of sulphuric acid. Pupae immersed in or floating on water, or lying on wet filter paper, failed to produce adults although they died only after they had reached an advanced stage of development.

Table VII.

Effect of humidity on pupae of L. suturalis.

Humidity conditions of pupae	No. of pupae	Percent. of pupae hatched.
Submerged in water	4	0
Floating on water	4	0
Lying on a wet surface	5	0
100% relative humidity	5	80
98% " "	5	80
90% " "	5	80
80% " "	5	80
75% " "	5	100
70% " "	4	100
65% " "	4	25
50% " "	4	0

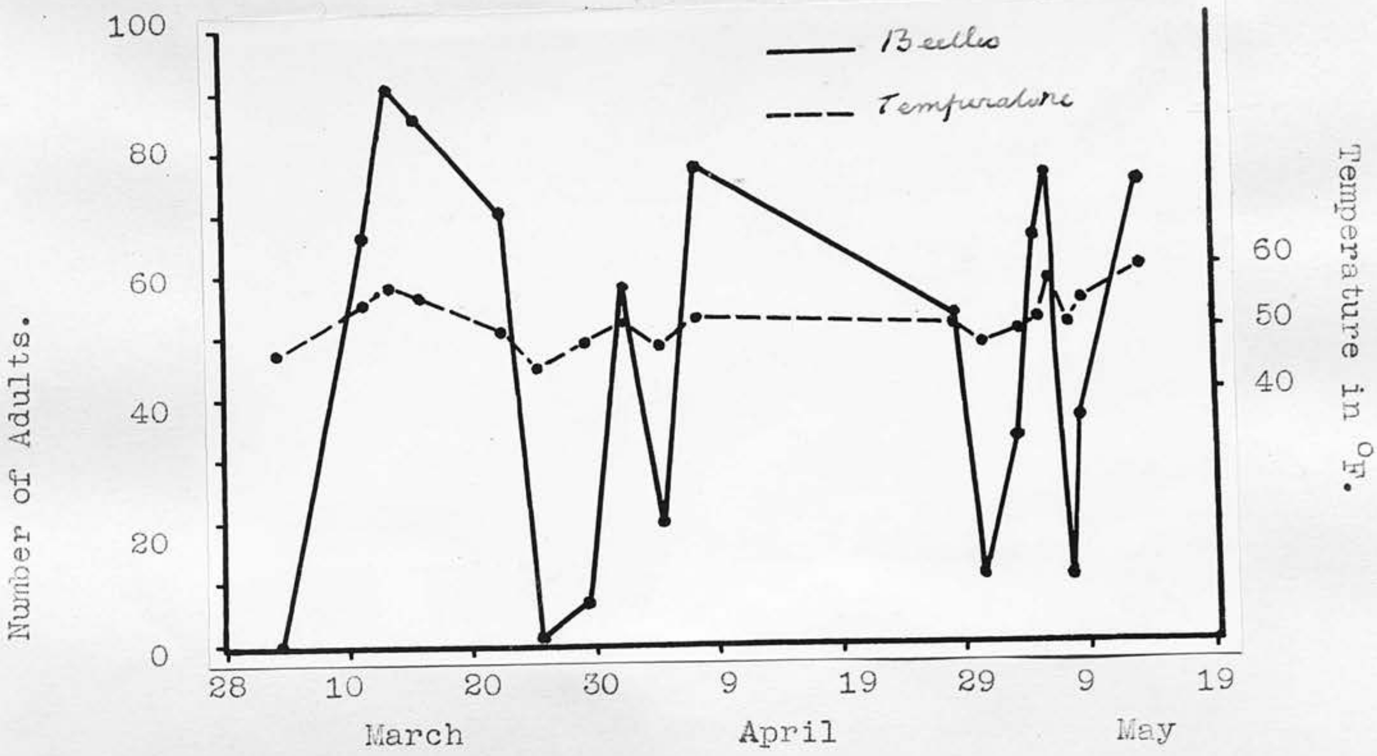
It /

It would appear from this experiment (Table VII) that the range of relative humidity best suited to the development of the pupae is 70% to 75%, but it is realised that experiments involving a larger number of specimens might give different results. It is apparent, however, that the pupae require a high percentage of relative humidity in order to develop successfully.

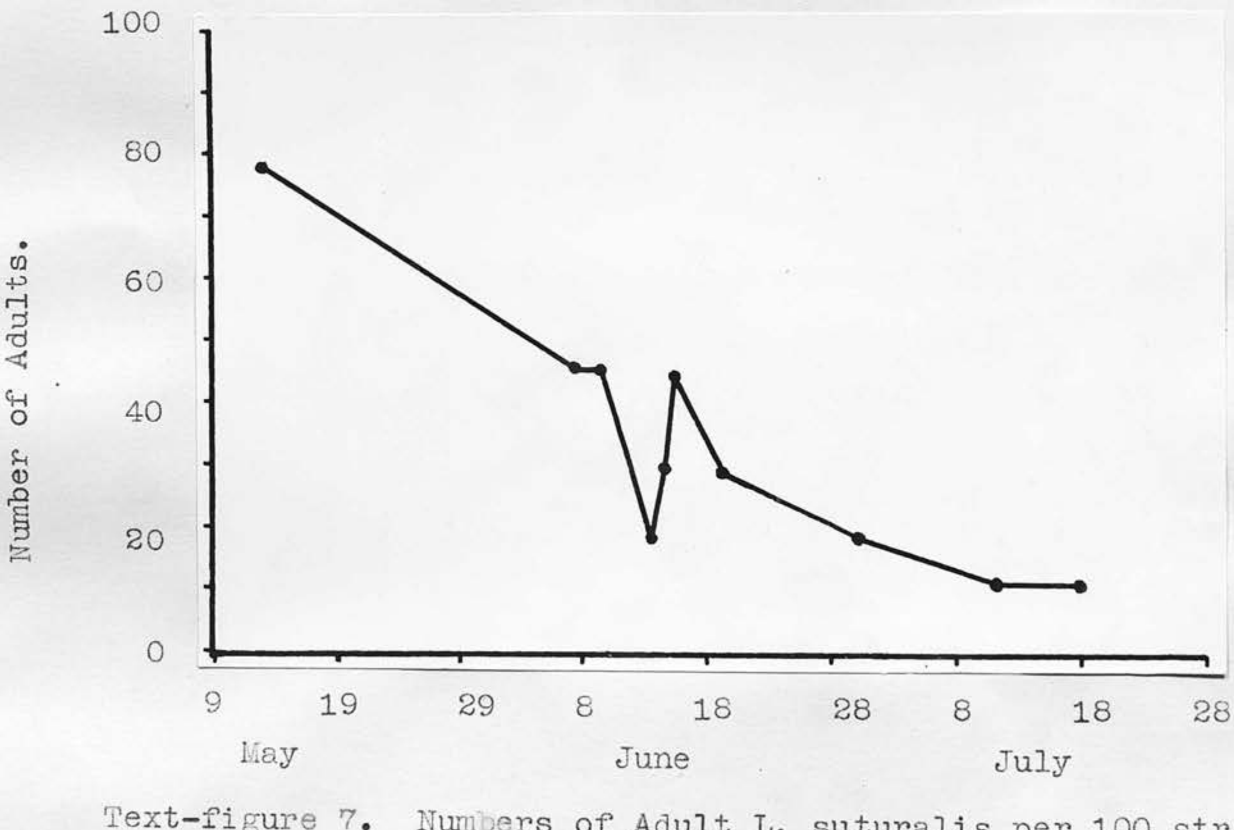
THE ADULT.

The adult (Plate I, fig, 1.) measures about ¼ inch in length. The head, thorax and abdomen are dark brown to black and the elytra vary from yellow to black. It has been noticed that in individuals from any one locality there is a tendency towards the same intensity of coloration, and immature beetles in autumn and early spring are darker than mature beetles in summer. The head, pronotum and wing covers are finely and closely punctate.

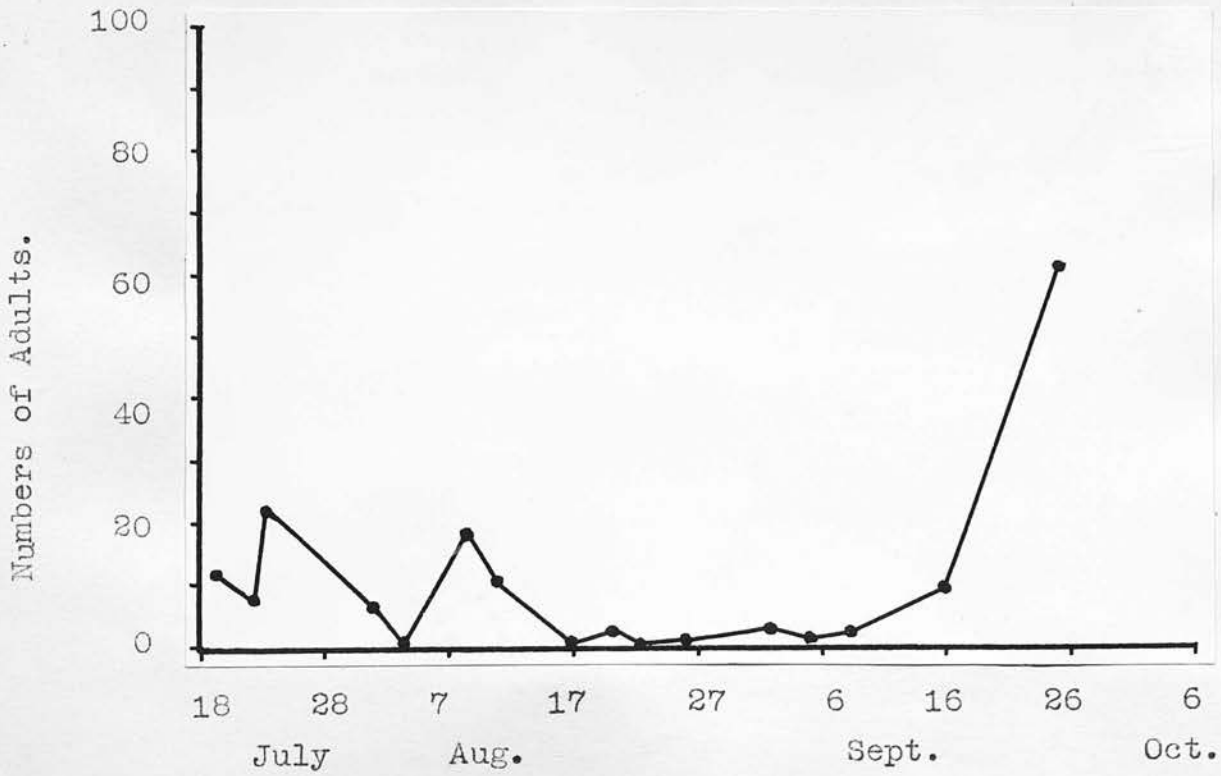
In text-figures 6 to 9 the numbers of beetles in each sample shown in Table II are plotted against the dates of samplings, and in text-figures 6 and 9 of the spring and autumn samples respectively, the average air temperatures at the time of sampling are also shown. Text-figures 6 to 9 show that beetles were abundant in autumn and spring, hibernated during the winter and became scarce from July to September. Slight overlapping of the beetles /



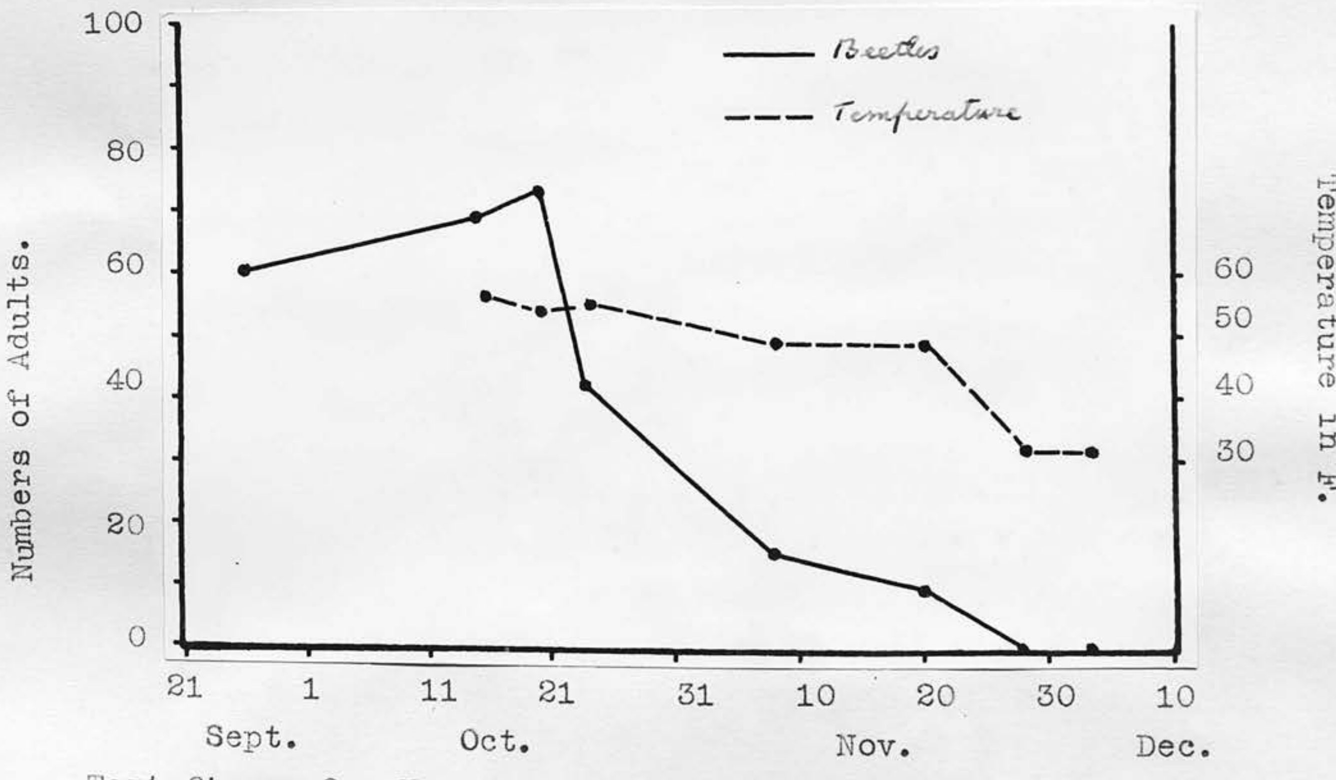
Text-figure 6. Numbers of Adult L. suturalis per 100 strokes of sweep-net captured in various localities between March 4th and May 13th, 1938, with corresponding temperatures.



Text-figure 7. Numbers of Adult L. suturalis per 100 strokes of sweep-net captured in various localities between May 13th and July 19th, 1938.



Text-figure 8. Numbers of Adult L. suturalis per 100 strokes of sweep-net captured in various localities between July 19th and Sept. 26th, 1938.



Text-figure 9. Numbers of Adult L. suturalis per 100 strokes of sweep-net captured in various localities between Sept. 26th and Nov. 28th, 1938, with corresponding temperatures.

beetles of the two generations occurred during this last period but is not shown in the graph since the individuals of the two generations were not separated.

In text-figure 6 it is seen that the beetles were fairly abundant on the heather when the temperature was above 48°F. At lower temperatures they remained inactive in the soil debris. Similarly, text-figure 9 shows that the beetles became progressively fewer on the heather as the temperature fell. The temperatures shown in Table II and text-figures 6 and 9, which were recorded when collections were made, usually in the early afternoon, were approximately the maximum daily temperatures. The night temperatures were much lower. Beetles kept in captivity on clumps of heather out of doors burrowed into debris for hibernation when the minimum temperature fell below 48°F., and remained there, with few exceptions, even when the temperature rose above this figure for several hours. Their behaviour differed in response to rises of temperature in autumn and spring.

Much smaller numbers of beetles were caught in warm days in winter than in autumn and spring in the same locality. That is, only a small proportion of the population respond to a rise in temperature at this season.

There are two variable factors to be noted in connection with the above data. One is that the samples were not all collected from one locality, and the other, that prevailing weather conditions governed /

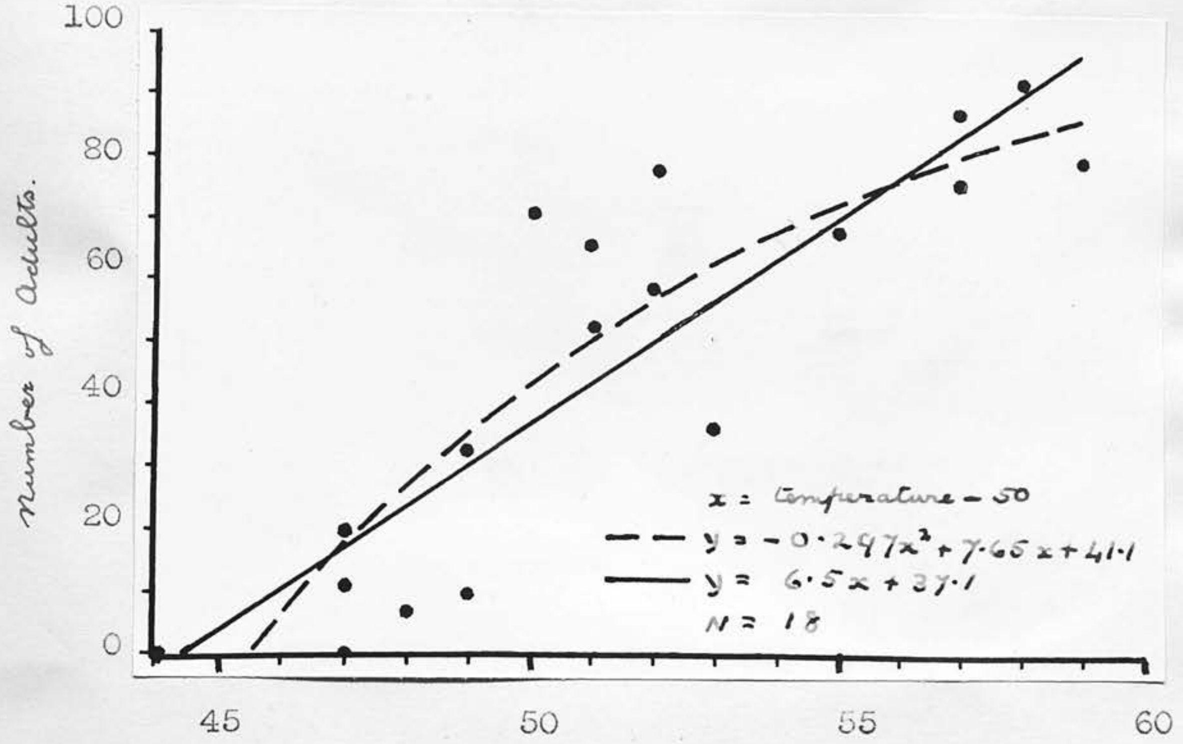
governed in great measure the number of beetles captured. The influence exerted by temperature in autumn and spring has been mentioned. Wind velocity was a factor of great importance at all times, and when a strong wind was blowing, few beetles were captured by the sweep-net, even during times of high temperature and bright sunshine.

Effect of temperature in spring.

In spring, there is little change in the population of the heather-beetle and therefore, the number of adult beetles captured per 100 sweeps of the net at this time should depend only on activity.

That there is a strong positive correlation between temperature and catch is clearly shown in text-figure 10. From the straight line regression $y = 6.5x + 37.1$ (correlation = 0.86) it is seen that, on an average, the catch is increased by 6 or 7 beetles for each unit rise in temperature. Inspection of the diagram shows, however, that the points representing the catch at low and high temperatures tend to give values below, and those at middle temperatures values above, the line. Further, it is obvious from a biological point of view that a temperature must be reached above which no further increase of catch would be possible.

Both mathematical and biological reasoning thus indicate that the true nature of the regression is a curved line with rapid increases in numbers per unit rise in temperature at low temperatures, /



Temperature in °F.

Text-figure 10. Scatter diagram of the relationship between air temperature and the numbers of Adult L. suturalis caught per 100 strokes of sweep-net in various localities between March 4th and May 13th, 1938 (same data as in Text-figure 6).

temperatures, and much smaller rises, finally becoming zero, at higher temperatures. This is shown by the parabolic regression $y = -0.297x^2 + 7.65x + 41.1$ fitted to the data. From this it can be said that the increase of adult beetles captured per 100 strokes of the sweep-net per unit rise in temperature is about 10 between 45°F. and 50°F., and about 3 between 55°F. and 60°F.

Thanks are due to Dr. C.B. Williams, Rothamsted Experimental Station, Harpenden, and Dr. A.C. Aitken, Edinburgh University, for their kind assistance in calculating the regressions.

Flight.

From spring onwards the beetles readily take to the wing during warm sunny weather. Their flight appears to be more or less indeterminate and they are carried along by the breeze for short distances. When the wind is strong the beetles rarely take wing.

During the course of the present investigation swarming flights were not observed, but the occurrence of swarms in Scotland has been recorded on several occasions in recent years. In May 1936, to quote one observer, " millions of beetles were seen on the shores of Loch Awe," and "the water was covered with their struggling bodies and trout were greedily devouring them." In the same year in South-west Scotland "on a fine day they were continually on the wing flying down wind" and large swarms were seen on April 9th. Large numbers were also observed in flight in Ayrshire early in May. Betrem (1929) reported that swarms were witnessed in North Germany and in Holland in 1928 and, as already mentioned, /

mentioned, Cornelius (1858) recorded such an occurrence on the continent as far back as 1853.

That these flights represent a means of dispersal and not a definite migration is clear both from the accounts of others and from our own observations. The occurrence of swarms is probably due to the presence within a limited area of large numbers of beetles which tend to disperse by flight after the heather has been severely damaged and thereby rendered useless for their continued maintenance. It is unlikely that these swarms always serve to infest new areas. Indeed, there is evidence that the beetles sometimes settle on ground which is quite unsuitable for breeding.

Sex ratio.

The numbers of each sex were counted in fifty collections of the beetle made, by sweeping, between December, 1937 and October, 1938. Of the total, 1166 proved to be males and 1938 were females, representing percentages of 37.56 and 62.44 respectively. Only in five of the collections were males more numerous. The sex ratio was also determined in individuals reared from pupae. For this purpose one hundred pupae were collected during September, 1937 and fifty of them hatched. Of these 21 were found to be males and 29 were females, giving percentages of 42 and 58 respectively. There was no apparent progressive reduction in the number of males from autumn to summer. /

summer. The percentages of the sexes varied widely when individual captures were compared; variation occurred not only among collections made within a few days of each other, but also among collections made at different times of the same day in the same locality.

Pairing.

In Scotland, pairing of the sexes was found to occur on the ground or on heather in April and May. From the time that beetles were first collected in spring, individuals were dissected at regular intervals and examination showed that spermatozoa did not occur in the spermathecae of females in which the ovaries were not ripe. That is to say, pairing occurs only after the ovaries have matured, and neither ovaries nor testes show signs of developing before the beetles resume feeding in the spring. It is not until late April that the ovaries begin to develop, and the ova are ripe about twelve days later.

That pairing occurs in spring has been verified by Grimshaw (1911), Cameron (1937), and Morison (1938). Betrem (1929) was of the opinion that the beetles pair in September before entering hibernation, and that coition very seldom occurs in spring. He recorded that Van Giersbergen found vast numbers of beetles copulating on heather in October. In Germany, on the other hand, Prell (1929) observed pairing in April and denies that the beetles pair in /

in autumn. He is also at variance with Dutch observers who maintain that the males disappear after the autumn pairing, whereas he found the sexes to be present in approximately equal numbers in April.

Later it will be demonstrated that the beetles can be induced to breed indoors without interruption provided the temperature remains sufficiently high. It is suggested, therefore, in explanation of the apparent difference in the breeding habits of the heather-beetle in Holland, as contrasted with Germany and Britain, that in the infested areas of Holland the climate may have been sufficiently mild in autumn to permit of the development of the gonads and of pairing of the sexes before the onset of winter.

Oviposition.

Beetles captured in the field on the 30th April were found to have begun egg-laying. To determine the duration and extent of oviposition, twenty-four pairs of beetles were segregated in glass vials, one male and one female per vial. It was possible by this means to record the number of eggs laid daily by individual females. Heather twigs were provided as food and were kept fresh by a band of wet cotton wool wrapped around the base of each. Eggs were readily laid on the damp cotton wool, sometimes on the heather shoots and occasionally even on the damp walls of the tube. Although /

Although the air within the tubes was saturated with water vapour, adequate aeration was provided by covering the open ends of the tubes with muslin. After oviposition began, it continued throughout the rest of the life of the female. In this experiment, the results of which are recorded in Table VIII, the first two pairs of beetles were segregated on the 30th April, the remainder on the 6th May, 1937.

Table VIII.

Number of eggs per day laid by 24 females of L. suturalis.

No. of specimen	No. of eggs laid	Longevity of females in days	Average No. of eggs/day	No. of specimen	No. of eggs laid	Longevity of females in days	Average No. of eggs/day
1	0	9	0.0	13	240	66	3.64
2	158	58	2.72	14	0	11	0.0
3	229	71	3.15	15	116	66	1.76
4	96	44	2.18	16	271	92	2.95
5	69	42	1.64	17	140	71	1.97
6	289	88	3.28	18	37	23	1.6
7	1	6	0.17	19	207	88	2.35
8	42	20	2.10	20	126	39	3.23
9	13	11	1.18	21	202	70	2.89
10	240	92	2.61	22	38	24	1.58
11	236	92	2.57	23	124	84	1.48
12	0	10	0.0	24	60	32	1.87

It was calculated from Table VIII that the average number of eggs per day per individual female was 2.52, the average total number of eggs per individual was 175 and the average period of oviposition was 68 days. Only those individuals were considered which lived for more than /

than thirty days after the beginning of the experiment. Although some of the beetles had begun egg-laying before segregation it is believed unlikely that the real average period of oviposition is much greater or the number of eggs laid per individual much larger than the figures presented above.

The total number of eggs laid by the sixteen beetles considered was 2800 and the total number of beetle-days from the beginning of oviposition until the death of all sixteen beetles was 1709. The number of eggs per day was not uniform and the variation is shown in Table IX.

Table IX.

Frequency of number of eggs laid per day by 16 females of L. suturalis.

No. of eggs per day	Frequency of each number	No. of eggs per day	Frequency of each number
0	638	11	10
1	42	12	3
2	33	13	1
3	23	14	4
4	25	15	4
5	44	16	0
6	38	17	2
7	47	18	1
8	44	19	2
9	42	20	0
10	63	21	1

Inspection /

Inspection of Table IX shows that on 638 beetle-days oviposition did not occur. On the days on which oviposition did occur, ten eggs, which correspond to the number of ovarian tubules, was the number most frequently laid. The number of days on which more than ten eggs per day was laid was 28, whereas on 338 days the number per day was less than ten.

Hibernation.

There is but one generation of the heather-beetle per annum; the immature adults pass the winter in a dormant or semi-dormant condition in soil debris or in moss and become sexually mature in spring. It has been remarked previously, with reference to text-figure 9, that once the beetles have entered hibernation they tend to remain inactive until spring, and when warm weather (above 50°F) is experienced in winter only a small proportion of the total population respond by leaving their winter quarters to feed on the heather.

The term diapause in entomology has been applied to periods of dormancy which may occur at one or other stage of an insect's life history, without reference to inducing causes. Often however it is restricted to periods of suspended animation occurring at a definite time of year when the prevailing environmental /

environmental factors (temperature and humidity) are such as would normally favour the continued activity of the insect. Interpretation of the phenomenon has been varied. Whereas Uvarov (1928), for example, attributes its occurrence to causes directly or indirectly related to the environment, but complicated by an acquired developmental rhythm, Decoppet and others, as described by Cousin (1932), have defined diapause as the expression of an heredity rhythm independent of the environment. Cameron (1937) considered that such a rhythm occurred in L. suturalis and inhibited the activity of the gonads which in field specimens do not develop to any marked degree until the spring.

The idea of the inhibition of gonadial activity in L. suturalis as due to the operation of an hereditary rhythm was tested by experiments in the laboratory. In Tables X to XII are recorded the results of experiments designed to show, firstly, whether beetles collected out of doors during winter could be induced to oviposit indoors by exposing them to temperatures higher than those normally experienced at this time; secondly, whether beetles collected in autumn could be induced to oviposit after exposure to freezing, and thirdly, whether beginning with eggs laid in the spring, a continuous series of generations could be bred throughout the seasons under conditions suitable for breeding.

In /

In the first problem, one sees from Table X that, among beetles taken from hibernation, egg-laying began, on seven occasions, within a few days at temperatures of 25°C. (77°F.) and over. Where the females died without laying eggs, dissection showed that the ovaries had begun to develop. Therefore it is is evident that egg-laying may proceed at any time of the year provided the temperature is suitable.

Table X.

Effect of increased temperature on hibernating adults of L. suturalis.

Date when collected	Date when placed in incubator	Temp. in °C. of incubator	No. of specimens ♂	♀	No. of days before first oviposition	Longevity of females which did not oviposit, in days.
19. 9.37	22. 9.37	15.5	25	35	-	47
"	".	20	25	35	-	28
"	"	25	25	35	9	-
"	"	30	25	35	6	-
20.10.37	21.10.37	20	12	15	-	37
"	"	30	12	15	6	-
5.11.37	6.11.37	30	12	16	9	-
1.12.37	6.12.37	30	4	2	-	25
20. 1.38	21. 1.38	25	2	6	8	-
24. 2.38	25. 2.38	25	10	19	15	-
22. 3.38	1. 4.38	25	50	54	5	-

Table XI. /

Table XI.

Effect of freezing on oviposition of L. suturalis collected in autumn.

Date of collection	Date when placed in refrigerator 0°C.	Date when placed in refrigerator -5°C.	Date when placed in incubator	Temp. in °C. of incubator	No. of specimens ♂	No. of specimens ♀	No. of days before first oviposition	Longevity of females which did not oviposit, in days.
10. 9.37	14.9.37	-	10.11.37	30	32	34	12	-
19. 9.37	22.9.37	-	11.10.37	20	8	15	-	24
"	"	-	12.10.37	30	8	15	8	-
"	"	2.10.37	8.10.37	20	12	18	-	24
"	"	"	"	30	12	18	-	24
27. 9.37	29.9.37	-	6.11.37	22	5	10	-	14
"	"	-	"	21	5	10	-	20

That beetles collected in autumn will oviposit, provided the temperature is suitable, even after being subjected to freezing is clear from an inspection of Table XI. In this experiment, where beetles died without laying eggs, dissection showed that the gonads were developing.

Table XII. /

Table XII.

Record of continuous breeding of L. suturalis indoors from May 1937 to January 1938.

Serial no. of generations reared in laboratory	Temp. in ^{o}C. to which adult beetles (Parents) exposed	Temp. in ^{o}C. at which eggs incubated	Temp. in ^{o}C at which larvae and pupae developed	Average duration of development from egg to adult, in days.
I	15.5	17.5	15.5	69
II	25	20	25	38
III	25	25	25	38
IV	25	25	25	40

Table XII shows that, although there is normally but one generation of the beetles per year, four successive generations were reared without interruption in the laboratory in less than 9 months. The eggs of the first generation of beetles were laid by overwintering adults caught in May, 1937, and, out of doors, these would not have developed to complete maturity until 1938. The adults of the fourth generation, of which there were but four, emerged from the pupae between 29th December 1937 and 3rd January 1938.

The adults of each successive generation became progressively paler but this is perhaps not surprising since individual beetles collected out of doors and kept in an incubator at 25^{o}C. (77^{o}F.) likewise turned pale in about ten days. There is an apparent correlation /

correlation between temperature and the degree of pigmentation.

In the laboratory there was observed a progressive loss of fecundity and vigour in successive generations of beetles reared there. This was indicated by the marked reduction of the number of eggs as compared with the average number of 175 which was laid by beetles collected in the field, and by the smaller percentage of eggs and larvae of generations I, II and III which completed development. This is set forth in Table XIII.

Table XIII.

Loss of fecundity and vigour in successive generations of L. suturalis reared indoors.

Generation of parent beetles	Average No. of eggs laid per female	Percent. of eggs hatched	Percent. of eggs which completed development to the adult	Percent. of 1st instar larvae which completed development to the adult
Overwintering beetles	175	-	-	-
Generation I	27	37	17	45
Generation II	17	30	4	13
Generation III	10	19	2	11

In Table XIII the data relating to the percentage hatch of eggs laid by the overwintering adults and the percentages of eggs and larvae completing development to the adult stage of the first /

first generation in the series was incomplete and was not included. The reduction of egg-laying and the increased mortality of each succeeding generation was possibly correlated with the increased rate of activity due to the high temperature of their environment and also with the quality of the heather which, as Thomas (1937) showed, becomes progressively less nutritious as the seasons advance. Both the sexually mature females and the young larvae normally feed on the buds and tender young shoots of heather in early summer, a rich food supply that was not available to the later generations reared experimentally indoors.

The results of the experiments presented in Tables X and XII show, that in the life cycle of the heather-beetle, there is no obligatory diapause or interruption of development, that is, there is no expression of an hereditary rhythm which is independent of the environment. Development of the gonads does not occur until spring because of the existence of adverse environmental factors, chiefly low temperature, which renders the beetle temporarily inactive in winter.

Effect of freezing.

In nature, the hibernating beetles are at times subject to severe weather conditions, to heavy rainfall and low temperatures. Since /

Since the beetles do not burrow deeply into the soil but lie dormant in moss and soil only two or three inches below the surface, little protection is secured against frost which penetrates quickly to that depth.

To test their resistance to freezing, beetles captured by sweeping infested heather in autumn 1937 were subjected in batches to 0°C. for periods varying from 26 to 87 days. (Table XIV). In the refrigerator, the beetles were kept in gauze covered tubes each containing a small quantity of loose, moist sphagnum.

Table XIV.

Effect of exposure to temperature of 0°C. to -1°C. for 26 to 87 days on adults of L. suturalis in autumn 1937.

No. of days' exposure to 0° to -1°C.	No. of beetles exposed.		No. of beetles surviving exposure		Percent. of beetles surviving exposure.	
	♂	♀	♂	♀	♂	♀
26	34	87	34	83	100	95.4
27	33	32	32	30	97	93.7
37	33	-	23	-	62.4	-
50	-	79	-	17	-	21.5
57	71	114	1	22	1.4	19.3
80	57	74	0	0	0	0
87	-	56	-	0	-	0

It is seen from Table XIV that a four weeks' exposure to temperatures /

temperatures of 0^{o} to -1^{o}C. has no appreciably injurious effect on one or other sex of the beetles, and that more than 60% of the males withstood 5 weeks', and about 20% females, but only 2% males, 8 weeks' exposure to these temperatures. None, however, survived 11 weeks of this treatment. The majority of the survivors were found to be still alive six weeks after their restoration to out of door conditions.

In a second experiment, nineteen beetles taken from hibernation were exposed, in January 1938, to 0^{o}C. and another eighteen to -5^{o}C. for three days. The same batches were later submitted to a second exposure, to -9^{o}C. and -12^{o}C. respectively. In the interval between the two exposures the beetles were kept out of doors. It was found that the beetles withstood a temperature of -5^{o}C. for three days, but that they were injured by exposure to -9^{o}C. and -12^{o}C. for three, or fewer days.

Because of the low temperature, and the water-retentive capacity of sphagnum, the habitat of the hibernating beetles in moss and soil debris is one that is kept very wet by the heavy winter rainfall. Thus, in nature, beetles are subjected to low temperature in an atmosphere of high relative humidity. To discover the optimum conditions of relative humidity under which their resistance to freezing was greatest small batches of beetles /

beetles were subjected to a temperature of $0^{\circ}$to $-1^{\circ}C.$ at various humidities. The beetles were placed in dry muslin-covered glass tubes which were enclosed in sealed jars containing sulphuric acid of different concentrations. The percentage of beetles alive in each tube after 21 and 37 days was estimated and the results are tabulated in Table XV.

Table XV.

Effect of humidity on L. suturalis exposed to freezing.

	No. of beetles exposed to 0° to $-1^{\circ}C.$			Percent. alive after 21 days' exposure			Percent. alive after 37 days' exposure		
Relative humidity	♂	♀	♂+♀	♂	♀	♂+♀	♂	♀	♂+♀
100	2	14	16	100	86	88	0	57	50
90	10	6	16	40	100	63	20	100	50
80	8	8	16	75	100	88	0	75	38
70	6	10	16	33	60	50	33	40	38
60	10	6	16	20	100	50	20	33	25
50	6	6	12	0	67	33	0	0	0

It would appear from Table XV that high relative humidities favour the resistance of the beetles to temperatures of 0° to $-1^{\circ}C.$ After 21 days 88% of the beetles were alive when the relative humidity was 80% and 100%, but only 50% alive when it was 60% and 70%. After 37 days 50% of the beetles were alive when the relative humidity was above 90% and only 38% alive when it /

it was 70% and 80%. Inspection of Table XV also shows that the death rate was higher in the males than in the females.

From these experiments it is permissible to conclude that the beetles can withstand long periods of exposure to temperatures at or just below freezing point, and that they are better able to endure prolonged exposure to freezing in an environment of high than in one of low relative humidity. Exposure for three days to a temperature of -5°C. (23°F.) can be withstood by the beetles without injury, but the majority are not resistant to temperatures of -9°C. (16 degrees F. of frost) or under, for even one or two days. It is also shown that the males are less hardy than the females. In consideration of the resistance of the beetles to freezing, it can be concluded that, in Scotland, frost is unlikely to be an important factor of control.

FOOD PLANTS.

The chief and perhaps the only food plant of the heather-beetle in nature is ling heather, *Calluna vulgaris*. Morison (1938) recorded that bell heather, *Erica cinerea*, may be slightly attacked by the beetles; but larvae which were kept in the laboratory and supplied with sprigs of *E. cinerea* or *E. tetralix* from the time of hatching failed to mature. It is probable, therefore, that the occurrence of larvae on *E. cinerea* is accidental since this plant frequently grows mixed with ling; in /

in our observation, eggs of L. suturalis were never found far from the latter plant. Attempts to rear the larvae on black crowberry, Empetrum nigrum were equally unsuccesful.

SUMMARY OF LIFE CYCLE OF L. SUTURALIS.

There is but one generation of the heather-beetle per annum. Winter is passed by the immature adults which hibernate in moss, in soil debris, or just beneath the surface of the soil to a depth of one or two inches. Beetles, however, may occur on heather in limited numbers in winter when the air temperature is above 48°F.

Development of the ovaries begins about the end of April, and ripe ova first appear early in May. As sperms have only been found within the spermathecae of females with mature ovaries, it can be assumed that mating occurs only when the ova are ripe.

The eggs are laid on sphagnum, in very small numbers at first, beginning in mid-April, but in larger numbers in late May or early June. Once egg laying begins, it is continued during the remainder of the life of the female, averaging 2.5 eggs per day for a period of about seventy days. In July adults become progressively less abundant, and only a few persist until mid-August.

Incubation /

Incubation of the eggs lasts three to four weeks in nature and 18 or 19 days at a constant temperature of 63^{O}F. Hatching of the larvae begins in early June and the young larvae climb the heather plants and feed on the young shoots and leaves. Larvae reared in the laboratory at air temperature, approximately 60^{O}F., completed the first instar in 9.1 days, the second in 7.4 days and the third instar in 7.6. days. During 1937 first instar larvae were most abundant in the field on the 23rd June, the second instar on the 13th July, and the third instar larvae on the 2nd August. During 1938 the corresponding dates were 10th July, 25th July and 9th August. It would appear, therefore, that each larval instar lasts two to three weeks under field conditions.

The pupae are first found at the beginning of August but they are most abundant from late August to late September. Pupation occurs in the same situations as those in which the adults hibernate, namely, in sphagnum, or just beneath the surface of the soil, and larvae which pupate in the soil form loose earthen cells within which the pupae lie.

The prepupal stage of the last larval instar along with the pupal instar averaged 26.3 days at the laboratory temperature of 60^{O}F. and probably take four or five weeks in their natural habitat. At a constant temperature of 77^{O}F. the prepupal stage was found to be 5.9 days and the pupal instar of 6.6 days so that /

that they are roughly of equal duration.

The adults begin to emerge in the latter half of August but do not become abundant until late September. It will be seen, therefore, that a slight overlapping of generations occurs, since the adults of the two generations may co-exist in small numbers during the latter half of August. The beetles become less active as winter advances and enter hibernation when the maximum temperature drops below 48°F.

Ling heather, Calluna vulgaris, is the chief and perhaps the only food plant of the heather-beetle.

NATURAL ENEMIES OF L. SUTURALIS.

Degeeria collaris Fall.

A species of Tachinid fly, D. collaris, was the only internal parasite of L. suturalis encountered. The parasite was identified by Mr. McHardy and the identification confirmed by a member of staff of the Natural History Museum, London. The third larval stage of this insect was described by Thompson (1920) who found it parasitising the elm leaf beetle, Galerucella luteola, in Italy in the spring.

As part of the routine of the investigation, beetles were collected from various localities and kept under observation in glass jars. In 1937 on the 7th July, a puparium was found among heather /

heather in one of the jars. Its presence suggested the beetle as being the host. On the 10th, a dipterous maggot was found crawling in the jar, and another on the 17th. These were removed and one was placed on damp sand, the other on damp cotton wool where they immediately pupated. Two beetles with abnormally swollen abdomens were dissected on the 18th and in each a single larva was found. Both pupated and from one of the pupae an adult fly developed, despite the premature removal of the maggot from the host. In each of the parasitised beetles, the contents of the abdomen had been destroyed by the parasite. Further observation showed that the host dies about an hour after the emergence of the parasite through the anal aperture of the beetle. Observations on the life history of D. collaris, etc., and the percentage of parasitised beetles caught in June and July, 1937 are recorded in Tables XVI and XVII.

In 1938 beetles were collected at intervals in various localities, from the time they first displayed activity in spring. The beetles were kept in captivity to ascertain whether they were parasitised and to determine approximately the date when they are first attacked by the parasite. Parasitised beetles were first found on July 1st. Of 25 beetles captured, 5 individuals or 20 per cent, were parasitised; the dates on which the maggots emerged from their hosts and the sexes of the parasitised beetles were, /

were, however, not recorded.

Table XVI.

Duration of pupal instar of D. collaris, sex of host and sex of parasite. †

Sex of host.	Date parasite emerged from host.	Date adult fly emerged from puparium.	Duration of pupal instar.	Sex of adult D. collaris.
*	7.7.37	-	-	-
*	15.7.37	-	-	-
*	17.7.37	-	-	-
♂	18.7.37	4.8.37	17 days	♀
♀	"	-	-	-
♀	20.7.37	31.7.37	11 days	♂
♀	"	-	-	-
♂	21.7.37	6.8.37	16 days	♂
♀	23.7.37	10.8.37	18 days	*
♀	24.7.37	-	-	-
♂	26.7.37	-	-	-

† 2 larvae on the 18th, 1 on the 20th and 1 on the 24th July were dissected from their hosts.

Sex not determined.

Table XVII.

Percentage parasitism of adult L. suturalis collected in summer 1937.

No. of beetles captured.	Date of capture.	No. of beetles parasitised.	Percent. parasitism.
*	28.6.37	1	*
15	15.7.37	8	53
5	21.7.37	2	40

* Not determined.

During /

During the autumn of 1938 intermittent collections of recently emerged beetles of the new generation were made before they had entered hibernation. Some of these beetles proved to be parasitised and the dates of emergence of the larvae from their hosts, of the flies from their puparia, the percentage of parasitism and sex of the hosts are recorded below and in Tables XVIII and XIX. In the autumn of 1937 parasitism was not observed among beetles collected in the field. When a beetle appeared to be parasitised, it was isolated in a glass tube containing a small quantity of damp soil. Between the 20th October and 11th November, eight larvae of D. collaris emerged from their hosts. Two of the parasitised beetles were males and six females. After the parasitic maggot had emerged from the host and pupated, the pupa was left undisturbed in the tube which was kept in the open all winter, but sheltered from rain. In late May the tubes were transferred to a large gauze breeding cage. When the flies hatched, twelve heather-beetles were introduced into the cage together with a turf of heather, and the beetles were replaced by fresh specimens every three days. Since the first two flies to emerge were males, and the third, a female, lived only three days, this attempt to induce the adult flies to oviposit was unsuccessful. The flies were supplied with split raisons, but they apparently did not feed.

Table XVIII /

Table XVIII.

Dates of emergence and longevity of D. collaris from puparia collected in autumn, 1938.

Date fly emerged from puparium.	Sex.	Date of death.	Longevity of adult.
15.5.39	♂	22.5.39	7 days
20.5.39	♂	2.6.39	13 "
29.5.39	♀	2.6.39	4 "

Table XIX.

Percentage parasitism of adult L. suturalis collected in October 1938.

No. of beetles captured.	Date of captured.	No. of beetles parasitised.	Percent. parasitism.
137	15.10.38	6	4.38
223	20.10.38	3	1.35
82	24.10.38	1	1.22

From Tables XVIII and XIX it is seen that the over-wintering generation of the fly spends approximately 7 months in the pupal stage and that 2.3 per cent of beetles captured in October, 1938 were parasitised.

The percentage of beetles parasitised in autumn 1938 (Table XIX) was less than that observed in the summers of 1937 (Table XVII) and 1938, but the number of beetles examined in summer was too small to be significant. The reduction of numbers of the heather-beetles in the spring of 1939 which became /

became more marked as the season advanced, precluded further observations on the parasitism of the heather-beetle by D. collaris. Apparently there are two generations per annum, one of which attacks the mature beetles in summer, the other the immature adults in autumn.

In the breeding vials kept in the laboratory, the sites selected by the larvae of D. collaris for pupation were varied. Some of the puparia were attached to the heather, and some to the underside of the gauze covering the tube; others again were found on the surface of the soil or cotton wool at the bottom of the vials; and, finally, a few occurred about half an inch below the surface of the soil.

The numbers of each sex of L. suturalis that were found to be parasitised were 5 males and 11 females. The relative proportion of the two sexes parasitised is not much different from that of the sex ratio of the beetle in nature, and the parasite probably does not show a preference for one sex more than it does for the other.

As the larva of D. collaris develops within the abdomen of its host, there is a marked distension of this region, and the hind end protrudes well beyond the apex of the elytra. This abdominal enlargement in females attacked in summer may be mistaken for normal swelling of the abdomen which accompanies development of the ovaries. But distension due to the growing maggot within the host is much more pronounced, and, in contrast to /

to the yellow colour of developing ova, the colour of the endoparasitic grub appears white through the stretched intersegmental membranes. In October 1938 a beetle was observed with its abdomen slightly swollen. Dissection revealed the presence of an immature third stage maggot of <u>D. collaris</u> within a sheath situated in the haemocoele near the base of the abdomen. The organs of the host beetle were still intact.

In July 1937 and 1938, the percentage of parasitised beetles appeared to be high, but this may be explained by the fact that in July few live beetles are to be found, since the majority of the females have died after the completion of oviposition and the males earlier after impregnation of the females in spring. Two explanations may therefore be offered for this high degree of parasitism; the first is that the parasite probably attacks the beetle only after their numbers have been depleted by other natural causes; the second is that parasitised individuals tend to outlive their unparasitised fellows.

In the course of this investigation beetles parasitised by <u>D. collaris</u> were obtained only from Balerno Moor on the Pentland Hills near Edinburgh. If they were present on other moors examined they must have been in such small numbers that they were readily overlooked. All the evidence points to the fact that <u>D. collaris</u> does not normally exert an effective degree of control on the heather-beetle.

<u>Coccinella</u> /

Coccinella hieroglyphica L.

This ladybird beetle (Plate II fig. 3) is the only predator which is numerous enought to effect a significant degree of control of the heather-beetle. From Tables I and II it can be seen that the life cycle runs parallel to that of L suturalis. The adults become active in spring, the larvae are active at the same time as the heather-beetle larvae and the new generation of adult ladybirds appears in late summer and autumn but somewhat earlier than the adults of L. suturalis. Like the latter, it is the adults of of C. hieroglyphica that hibernate.

Both the adults and larvae (Plate II fig. 4) of C. hieroglyphica prey on the larvae of L. suturalis, and in 1937, the predator was supplied in the laboratory with specimens of the latter in order that its predatory capacity might be gauged; this is shown in Tables XX and XXI.

Table XX.

Predatory capacity of adults of C. hieroglyphica for larvae of L. suturalis.+

Date of capture.	No. of days fed.	Host larvae eaten Total No.	No./day.
1. July 20th	32	3 2nd, + 13 3rd instar	0.50
2. July 20th	38	4 " + 16 " "	0.53
3. July 27th	33	1 " + 19 " "	0.60
4. July 31st	28	0 " + 19 " "	0.68
5. July 31st	28	0 " + 16 " "	0.57

+ The first two ladybird beetles were caught in the field; the remainder were hatched from pupae.

The average number of heather-beetle larvae eaten per day by the adult of C. hieroglyphica was 0.6, and by the larvae, 2.3, and the largest number eaten per day by one larva was 4 second-stage or 3 third-stage (Table XX and XXI).

Table XXI. /

Table XXI.

Predatory capacity of larvae of C. hieroglyphica for larvae of L. suturalis.

1. Date of capture.	No. of days fed.	Host larvae eaten. Total No.	No./day.
1. July 15th	3	8 2nd, + 0 3rd instar	2.66
2. July 17th	5	7 " + 0 " "	1.40
3. July 17th	3	7 " + 2 " "	3.00
4. July 17th	3	0 " + 5 " "	1.66
5. July 17th	3	4 " + 4 " "	2.60

The eggs of C. hieroglyphica have not been found but it is presumed that they are laid in spring. Adults beetles dissected in autumn 1937 and 1938 were found to have undeveloped ovaries and, although in the spring of 1938 eggs were neither obtained in the field nor found developing in dissected adults, lack of this discovery might be attributable to the comparative rarity of lady-birds at this season of the year, so that it was possible to examine the ovaries of only a few specimens.

The duration and season of the pupal instar is shown in Table XXII.

Table XXII.

Duration and season of pupal instar of C. hieroglyphica.

Date of pupation.	Date of emergence. of adult	Duration of pupal stadium in days.
July 18	July 31	13
"	"	13
"	August 3	16
July 20	" 2	13
"	" 3	14
"	" 3	14

Table XXII shows that in 1937 the average pupal stadium was about /

about 14 days and that the adults emerged in late July and early August. By inspection of Tables I and II it is observed that the cycle was later in being completed in 1938 than in 1937 as also was that of L. suturalis.

It is considered highly improbable that C. hieroglyphica could increase its numbers sufficiently rapidly to terminate an outbreak of the heather-beetle. When the larvae of L. suturalis are abundant, a large percentage of Coccinellid larvae might be expected to reach maturity and consequently there would be an increase in the population of ladybirds in autumn as compared with spring. Field observations served to confirm this hypothesis, and adults of C. hieroglyphica were actually captured in greater numbers in autumn than in the spring of 1937 and 1938 (Tables I and II). But when the population of one year is compared with that of the preceding, no significant increase is observed. Adults of C. hieroglyphica were found to occur in relatively small numbers in the spring of 1937, 1938 and 1939, and, because of the scarcity of host larvae in 1939, the ladybird was also very rare in the autumn of that year. There would thus appear to be a high death rate in nature among the overwintering adults. In captivity, very few of those collected in 1937 and 1938 survived the winter.

That they are very tolerant to frost was shown by the survival of about fifty beetles kept for nearly seven weeks in a refrigerator at $0^{\circ}C$. in November and December, 1937, and of twenty subjected to $-5^{\circ}C$. for three days. The individuals submitted /

submitted to these low temperatures succumbed no more quickly nor in greater numbers than those kept continuously in the laboratory or out of doors. The majority were still alive early in February, but at mid-April, only a few survived.

There must be some factor other than low temperature that is responsible for their failure to overwinter successfully. As recorded in Table XX, three adults which emerged, one on the 27th and two on the 31st July, devoured 20, 19 and 16 heather-beetle larvae in 33, 28 and 28 days respectively. But by mid-September practically all the larvae of L. suturalis have pupated, and therefore from then until the ladybirds enter hibernation the food supply is reduced. It is not known whether C. hieroglyphica feeds on insects other than heather-beetle larvae. In September, 1938, small caterpillars were offered as food to captive adults of C. hieroglyphica and were refused. Betrem (1929) who considered this insect as being the principal enemy of the heather-beetle in Holland, pointed out that aphidae (plant lice) which are the prey of many species of ladybirds, are uncommon on heather. The life history of C. hieroglyphica differs from that of aphidivorous coccinellids such as Aphidecta obliterata which, according to Laidlaw (1937), is able to feed and breed until the beginning of winter.

It is suggested that deficiency of food in autumn is chiefly responsible for the comparative failure of C. hieroglyphica to overwinter, and that its rate of increase is thereby checked. /

checked.

Other insect predators.

Predaceous insects other than C. hieroglyphica that were captured on heather infested by heather-beetle belonged to the families Reduviidae (Assassin Bugs), Pentatomidae (Stink Bugs), Carabidae (Ground Beetles) and Cicindelidae (Tiger Beetles). The predatory tendencies of captured specimens were tested by confining them with larvae of the heather-beetle.

The species of Reduviidae found on heather were Nabis flavomarginatus Scholtz; N. ericetorum Scholtz; N. rugosus Linn; and N. ferus Linn. Only in one experiment was a larva of L. suturalis attacked by a bug and that was by a specimen of N. ericetorum. No species of bug occurred in numbers large enough to have any effect on the population of heather-beetle, even had they been predaceous on the latter.

Various large species of Carabidae and Cicindelidae were found to have voracious appetites. They ate large numbers of heather-beetles, both adults and larvae, supplied in captivity: for example, a specimen of the large Carabid, Carabus violaceus ate 5 to 6 adult heather-beetles per day for 5 days, when the experiment was discontinued. These insects are slow breeders, as compared with the heather-beetle, and it is considered unlikely that they would increase equally with the heather-beetle, or that they depend on L. suturalis for food. Consequently they /

they could not control the heather-beetle effectively.

Fungous and other diseases.

Whenever heather-beetles or their larvae were overcrowded in breeding jars in the laboratory, some invariably died, apparently as a result of the attacks of fungi or bacteria. In beetles parasitised by fungi, the mycelia and conidiophores developed externally, and, in individuals infected with bacteria, the body contents were reduced to a putrefying liquid mass. One species of fungus attacking the beetle was kindly identified as *Entomophthora lampyridarum* by Mr. Petch, King's Lynn, Norfolk. Betrem (1929) reported that in his breeding experiments several larvae which had made cocoons in the ground were parasitised by *Sporotrichum epigaeum*, a fungus which lives saprophytically in the soil.

Symptoms of attack were a swelling of the abdomen and a darkening of the intersegmental membranes. In the earlier stages of development of the disease, affected beetles were apt to resemble those attacked by *D. collaris* and this was especially true in the case of a non-fungous type of attack which occurred amongst captive beetles in October, 1938. The attack developed about seven weeks after their capture. After death, the beetles remained adhering to the food plants, and affected beetles would remain active for some time after the apparently healthy remainder had /

had entered hibernation.

Many thousands of heather-beetles of all stages have been captured in the field and none was observed to be diseased at the time of capture. It has not therefore been determined to what extent fungi and other organisms may serve to control the heather-beetle in nature.

INFLUENCE OF CLIMATIC FACTORS ON THE ACTIVITY OF L. SUTURALIS.

Since natural enemies were not found to be significant in controlling the heather-beetle, it is considered that physical factors may possibly limit the activities of the pest. It is generally recognised that climatic conditions can considerably influence the density of an insect population from season to season, either by altering the habitat or by acting on the insect directly.

Grimshaw (1911) believed that L. suturalis flourished best in a mild climate with high average rainfall, but that after a very wet winter, beetles were not so numerous as after a dry one. Conclusions hereafter reached are in agreement with the former belief, but no opinion can be offered with regard to the latter.

In Holland, according to Betrem (1929), mild winters were considered to be responsible for the epidemics of 1926 and 1927, but since beetles withstood long exposure to low temperatures under /

under experimental conditions, it is believed that in Scotland at least, severe frost is not a factor of natural control.

Morison (1938) accounts for the occurrence of epidemics in the following manner "....the attack is usually worst on rather flat marshy areas which become very dry during periods of drought .... the most important factor is lack of the usual amount of rain during July and August for two or three years in succession, which seems to favour the multiplication of the insect and to hinder the growth of the plants .... In N.E. Scotland I believe that the peak of an attack was in 1935 following the dry periods of 1933-34-35 ..... The heather plant in its normal environment requires a copious supply of water and it seems to be during a period of drought that it suffers most damage from the insect." Contrary to this opinion of Morison it must be emphasised that larvae were reared successfully under conditions of high relative humidity so that it appears unlikely that high rainfall in summer would directly inhibit their development. It is suggested, therefore, that if high summer rainfall had any adverse effect on the larvae this would probably be the result of attacks of entomophagous fungi and bacteria encouraged by increased humidity. From 1936 to 1938, heather-beetles were responsible for severe damage to heather in some districts, and these were summers of comparatively high rainfall. The average precipitation in July and August recorded at /

at four meteorological stations in Midlothian, Stirlingshire, Argyllshire and Ayrshire was in the period of 1932 to 1935, 4.99, 6.28, 6.56 and 3.72 ins. respectively, and in 1936 to 1938 it was 7.15, 8.15 and 7.04 ins. It is quite conceivable, however, that if a severe attack occurred in a year when summer drought was experienced, as in 1935, it might be more drastic in its effect on the heather.

That climatic conditions are, in fact, important in the control of the heather-beetle is shown by the following observations made during the course of the investigation.

Influence of drought in spring.

(1) In 1938, drought was experienced from early April to mid-May and the moisture conditions of the moors were altered considerably. On one area in the Pentlands, which was usually wet and boggy, the moss S. acutifolium became dried up despite its abundance and close growth. The effect of the drought was even more rapid on a nearby moor where the moss S. cymbifolium predominated and, although not ideal beetle ground, the area had suffered some damage from beetle attack. During the drought the beetles gradually became reduced in numbers and it was supposed that they had departed in search of conditions more suitable for breeding. The drought started just after the beginning of oviposition, and when the moss became dry, egg-laying ceased. Eggs which were laid while the moss was still damp finally perished /

perished from desiccation. Dissection of female beetles showed that the eggs were ready for laying and it was apparent that they were being withheld because of the lack of moist sphagnum etc. on which to ovipost. When the beetles were transferred to moist conditions indoors they laid eggs at once. When rainfall in late May restored normal conditions on the moors, oviposition was resumed, but in the above and other ares, observation showed that there was a decided reduction in the density of larvae in summer as compared with that in these same areas in the preceding year. Unfortunately a strict comparison cannot be drawn since the method of sampling the population was not identical during 1937 and 1938.

To test the effect of drought on the rate of oviposition, beetles collected in the field were confined in well ventilated zinc gauze cages. Sprigs of heather used as food for the beetles had their cut ends passed through a small hole in the zinc floor of each cage so that the water required by the heather was outside the cage. When it was desired to supply conditions approximately normal for egg-laying, moist cotton wool instead of sphagnum was placed on the floors of the cages. The results of the experiment are given in Table XXIII where the contrasting conditions are referred to as wet and dry and not in terms of relative humidity, since the factor investigated was the effect on oviposition of the presence or absence of a moist surface. Moreover, the open structure of the cages and their situation at an /

an open window ensured that the humidity would not differ greatly in the two conditions, except just above the damp cotton wool and the bare zinc floor respectively. Six males and six females were introduced into each of six cages A to F, and each experiment was discontinued when all but one female had succumbed. The beetles in each cage were subjected first to drought for a few days (see Table XXIII) and then to a humid environment, and the number of eggs laid per day was recorded.

Table XXIII.

Effect of drought on oviposition of L. suturalis.+

Number of eggs per female per day.

Cage A.	Cage B.	Cage C.	Cage D.	Cage E.	Cage F.
3.67	*0.00*	*1.50*	*1.67*	*0.00*	*0.00*
3.50	*0.00*	*1.83*	*0.00*	*0.17*	*0.00*
0.50	5.83	*1.67*	*0.00*	*0.83*	*0.17*
1.50	3.17	*0.33*	*1.33*	*1.33*	*0.00*
0.83	0.00	4.67	*0.00*	*0.17*	*0.25*
2.50	0.00	2.17	*0.00*	*0.00*	*0.00*
0.00	1.67	1.00	*0.00*	*0.00*	*0.00*
2.83	4.17	3.00	*0.00*	*0.00*	*1.25*
2.40	2.83	0.50	3.33	*0.00*	*0.00*
0.00	0.00	1.00	3.67	*1.25*	*1.25*
0.00	2.50	0.83	0.00	*0.00*	*0.00*
0.00	2.17	*0.17*	0.33	*1.33*	*0.00*
0.00	0.50	*0.67*	2.50	*0.00*	*1.00*
0.00	1.50	*0.50*	2.50	*2.67*	*0.00*
0.00	3.75	*0.83*	2.00	*0.00*	–
10.00	2.75	*1.20*	0.00	*2.00*	–
1.67	*0.00*	*0.00*	0.00	0.00	–
0.00	*0.00*	*0.00*	–	–	–
0.00	*1.00*	*0.00*	–	–	–
2.00	*2.50*	–	–	–	–
0.00	*0.00*	–	–	–	–
Averages					
1.90	2.20	1.88	1.59	1.00	–
0.00	*0.50*	*0.73*	*0.37*	*0.52*	*0.28*

+ Figures in italics refer to beetles kept in dry conditions.

Taking the females of all cages into account (Table XXIII), it was found that the average number of eggs per adult female beetle per day was 1.89 when the beetles were supplied with damp cotton wool on which to oviposit, and 0.44 when no damp cotton wool was provided, so that the former rate of oviposition was more than four times greater than the latter. Inspection of Table XXIII shows that, on being transferred from dry surroundings to a humid environment, the beetles reacted at first by laying a number of eggs that was much greater than the average. As an example, in Cage A, the beetles were provided with damp cotton wool for ten days and the average number of eggs laid per female per day varied from 0 to 3.6. During the following five days, damp cotton wool was not supplied, and on none of these days did oviposition occur. Humid conditions were then restored, and on the first day, an average of 10 eggs per female was laid which is much greater than the average of 1.9 per female per day for the whole 16 days during which the beetles were provided with moist cotton wool. Although the numbers of beetles employed in the experiments were small, the results obtained nevertheless confirm the observation that the rate of oviposition in the field is reduced when drought intervenes.

(2) In the spring of 1939, the rainfall from early April to mid-June was unusually low. In Scotland, the precipitation in May was only 44 per cent of the average for the period 1881 to 1915. /

1915. From mid-May to mid-June the weather was very warm and the humidity low. The maximum daily temperature occasionally rose to 80^{O}F., and, at Boghall farm on the Pentland Hills in the first week of June, the relative humidity was sometimes as low as 7% and did not rise above 50% until nightfall. Between May 16th and June 9th, less than 1 mm. of rainfall was recorded at this meteorogical station. This period of dry weather extended to a later date than did that of the previous year and was much more intense as regards its effect on vegetation and amount of ground moisture.

A survey of a large moor in Perthshire where extensive and severe beetle damage had occurred for five years was made in early June. The ground which is normally very boggy was dry and hard. The sphagnum which is everywhere plentiful had become dried and withered to a depth of 6 - 8 inches and was bleached white (Plate III, fig. 3). It was found that beetles had become very scarce in places where they had formerly been very numerous. Certain of these areas had been examined a month previously and beetles had been found in moderate numbers, though they were not quite so abundant as during the corresponding period of the previous spring when, however, actual counts of their numbers were not made. Thirty sample collections of beetles were made by means of a sweep-net and each sample represented the result of 100 strokes of the net. In one sample /

sample collected, in a favourable situation, 10 beetles were caught, and in another locality 5, whilst there were 4 samples in which 2 beetles were taken, and 5 with only 1. In the remaining 19, no beetles were caught. One should compare this with an average of 48 adult beetles per sample early in May. Eggs were difficult to find. Only in one damp locality near the source of a stream were a few eggs discovered; thirteen of these had been laid well down in the moss, while four laid near the surface had perished from the drought. The effect of the hot dry weather on the vegetation could be observed even in this area despire the supply of moisture from the nearby stream; it was here that the largest number of beetles was captured by sweeping.

During the following weeks other localities were visited and it was found that everywhere the beetles had been adversely affected by the drought. One locality is of special interest. An intense but restricted infestation was discovered in autumn 1938 on the Lammermuir Hills; the beetles were concentrated on a small embankment and so abundant were they, two thousand were caught by fifty consecutive strokes of the sweep-net. On the 18th April, 1939, beetles were still very numerous but had spread further afield and the density of population per unit area had thereby become reduced. On May 25th, a warm sunny day, beetles were active on the wing and still more widely dispersed. Female /

Female beetles, swollen with eggs, were experiencing difficulty in finding conditions suitable for oviposition. Some were observed crawling over a roadway far from heather. By the 18th June beetles had practically disappeared. Eggs were found in abundance, chiefly on the moss S. cymbifolium but many had been deposited on the bare soil beneath the moss, and on the lower parts of the stems of heather. Almost all the eggs had shrivelled and perished.

Outbreaks and climatic conditions.

It is conceivable that outbreaks of the heather-beetle might occur suddenly and uniformly over the whole country, but experience has shown that moorlands have not been attacked in the same degree everywhere at the same time. During the current outbreak, the year 1935 has been claimed as the one in which most severe attacks occurred. In 1936 the activities of the beetle appear to have been checked. In 1937 and 1938, however, there were several moors on which beetles were still present in large numbers. Examination of reports showed that beetle damage was observed in one locality in 1928. From then until 1932 damage was apparently slight, but it became very noticeable again in the next three years and was also widely spread. In three localities the ravages of the beetle were first noticed between 1927 and 1929 and observed to increase in extent /

extent from year to year. On the other hand, beetle damage was often noted only one or two years before the attack reached its greatest intensity. Reference to older records showed that the beetle was recognised as particularly injurious in 1889, 1902, 1907 to 1912 and 1922 to 1925.

The effect on the activities of the beetle of dry weather in spring 1938 and 1939 has been described above. The rainfall which occurred during these periods, from the beginning of April to mid-May (May 13th) in 1938 and from the beginning of April to early June (June 9th) in 1939, is given in Table XXIV along with that of the corresponding periods of the years 1931 to 1937 and was taken from records obtained at Boghall Farm, Midlothian. This meteorological station was not far distant from several infested moors which were kept under observation.

From Table XXIV, it is seen that in 1938 from April to mid-May the rainfall was 0.53 ins. and in 1939 from April to early June 2.74 ins., figures which were both considerably lower than in previous years, except that in 1936 comparatively low rainfall was also experienced during the same periods. As has been observed, the drought of 1938 retarded oviposition and that of 1939 practically eliminated the heather-beetle throughout the country. In 1938, precipitation was low during the early part of the breeding season from April to mid-May: from mid-May to early June the high rainfall, 5.57 ins, restored conditions suitable for breeding. On the other hand, in 1939, excessively low /

low rainfall, 0.4 ins., occurred during the latter part of the normal breeding season, i.e. from mid-May to early June and coincided with high temperature and low humidity (Table XXV).

Table XXIV.

Rainfall in inches recorded at Boghall Farm, Midlothian, 1931 to 1939.[+]

Period.[*]	1931	1932	1933	1934	1935	1936	1937	1938	1939	Average.
1. April to mid-May	3.68	4.23	*2.22*	5.18	4.02	*1.40*	*2.16*	*0.53*	*2.34*	2.86
2. Mid-May to early June.	5.16	3.26	*2.45*	*1.48*	*1.81*	*1.55*	3.70	5.57	*0.40*	2.82
Total	8.84	7.49	*4.67*	6.66	5.83	*2.95*	5.86	6.10	*2.74*	5.68

+ Figures in italics refer to rainfall which was below the average.

* The first period is from week no. 22 to 27, and the second period from week no. 28 to 31 of the Shaw year.

It is therefore considered that low rainfall was the principal climatic factor which checked the activities of the beetle in 1936. From April to early June there were only 2.95 ins. of rain. At the same time, the destruction of heather by the beetle previous to 1936 probably contributed towards its elimination in many localities. That the beetle was not everywhere eradicated in 1936 as in 1939 was probably due to the fact that in 1936, the rainfall was evenly distributed throughout the breeding season. In 1936, there were 1.4 ins. of rain from April /

April to mid-May, and 1.55 ins. from mid-May to early June. Also from mid-May to early June, the weekly mean temperatures were considerably lower and the humidities higher in 1936 than in 1939. In 1936, as compared with 1939 therefore, there would have been a lesser reduction both of ground moisture and of that retained by sphagnum so that oviposition and successful development of the eggs would not have been so drastically curtailed.

Table XXV.

Weekly mean temperatures and humidities at Boghall Farm, Midlothian, from April to early June, 1936 and 1939.+

Temperatures

			April			May				June
1936	39.9	40.8	37.2	44.6	47.9	50.7	53.9	48.6	47.2	50.6
1939	39.6	50.3	45.6	41.2	44.4	51.9	46.8	53.9	57.9	61.4

Relative humidities (9.0 a.m.)

			April			May				June
1936	82	78	74	80	74	88	81	85	79	78
1939	82	88	70	76	78	86	82	77	67	64

+ Weeks nos. 22 to 31 (inclusive) of the Shaw year.

During the whole breeding season of L. suturalis, from April to June, the average monthly rainfall recorded at four meteorological stations in Midlothian, Stirlingshire, Argyllshire and Ayrshire from 1932 to 1939 was respectively 8.50, 6.72, /

6.72, 8.38, 6.81, <u>5.18</u>, 6.28, 8.92 and <u>5.46</u> ins. Again it is seen that precipitation in 1936 and 1939 (in italics) was comparatively low.

It may be concluded that weather conditions in spring and early summer are important factors in determining the density of population of the heather-beetle. A sequence of wet springs encourages the beetle to multiply. On the other hand, it has been shown that a severe and prolonged drought in spring may practically cause its extermination. That moisture is all important for successful breeding explains why districts of high average rainfall have suffered most damage from the depredations of the heather-beetle.

CONTROL OF L. SUTURALIS.

Insecticides.

Field experiments in controlling the heather-beetle by means of insecticides were carried out in 1938 and 1939. In one set of experiments, the insecticidal properties of derris and of derris mixed with pyrethrum were tested upon the adult and larval stages of the heather-beetle.+ In another set of experiments, derris and pyrethrum were applied as wet sprays to heather infested by the larvae.* In each experiment the beetle population, adults or larvae, was estimated before and after dusting by collections made with a sweep-net; each collection or /

+ The derris powder was a preparation known as "Drymac No. 2" and the derris-pyrethrum powder was one known as "Flytox."

* The pyrethrum extract is sold as "Pysect" and the derris preparation as "Katakilla".

or sample represented the catch made by a definite number of strokes identical for each experiment. Details of the experiments and the results are tabulated in Tables XXVI to XXVIII.

Table XXVI.

Control of L. suturalis adults by insecticidal dusts.

(a) 559 sq. yds. dusted with derris (85 lbs./ acre) and 750 sq. yds. with derris-pyrethrum (65 lbs./ acre).

Date.	Time of sampling beetle population.	Air temp. °F.	Number of adult beetles. Area dusted with derris-pyrethrum.	Control Area.	Area dusted with derris.	Control Area.
6.5.38	Before dusting	57	93	79	56	62
"	At dusting	53	-	-	-	-
7.5.38	After dusting	49	4	10	1	9
8.5.38	"	53	9	40	3	29
13.5.38	"	59	66	103	18	53

(b) 1760 sq. yrds. dusted with derris (47 lbs./ acre) and 2420 sq. yds. with derris-pyrethrum (36 lbs./acre).

Date.	Time of sampling beetle population.	Number of adult beetles. Area dusted with.derris-pyrethrum.	Area dusted with derris.	Control area.
15.6.38	Before dusting	21	33	37
15.6.38	At dusting	-	-	-
16.6.38	After dusting	12	12	45
20.6.38	"	12	13	7
22.6.38	"	20	7	29

From Table XXVI (a), it is seen that five days after dusting the percentage of beetles on the area treated with derris-pyrethrum was approximately 67% of the beetles on the adjoining /

adjoining untreated area, and, on the area treated with derris, about 34% of those on the corresponding control area. The small number of beetles caught on the day after dusting was probably due to the prevailing low temperature. Table XXVI (b) shows that, although the day after dusting there was a decided reduction of the beetle population in the areas treated with dusts, collections made five and seven days after dusting indicated that the effect of the treatment did not persist very long. Moreover, in June, when the treatments were made, the weather is relatively warm, the beetles are consequently active and migration from one area to another is constantly taking place.

Table XXVII.

Control of L. suturalis larvae by insecticidal dusts.

(a) 420 sq. yds. dusted with derris (57 lbs./acre) and 924 sq. yds. with derris-pyrethrum (26 lbs./acre).

		Number of larvae		
Date	Time of sampling beetle population.	Area dusted with derris-pyrethrum.	Area dusted with derris	Control area.
1.8.38	Before dusting	117	137	144
2.8.38	At dusting	-	-	-
3.8.38	After dusting	44	14	188
4.8.38	" "	30	23	125

(b) 810 sq. yds. dusted with derris (60 lbs./acre) and 1602 sq. yds. with derris-pyrethrum (30 lbs./acre).

		Number of larvae		
Date	Time of sampling beetle population.	Area dusted with derris-pyrethrum.	Are dusted with derris.	Control area.
8.8.38	Before dusting	214	226	234
8.8.38	At dusting	-	-	-
10.8.38	After dusting	23	31	232
11.8.38	" "	67	113	222

Inspection /

Inspection of Table XXVII (a) shows that on the day following dusting, the population of larvae on the area dusted with derris-pyrethrum was reduced to 37%, and on the area treated with derris to 12% of that on the adjacent control area. Two days after dusting the corresponding percentages were 24 and 18. It is seen from Table XXVII (b) that two days after dusting the population of larvae on the area dusted with derris-pyrethrum was reduced to approximately 10%, and on the area treated with derris to 13% of that on the adjacent control area. On the following day the corresponding percentages were 30 and 59.

Table XXVIII.

Control of L. suturalis larvae by insecticidal sprays.

810 sq. yds. dusted with derris (60 galls./acre) and 225 sq. yds. with pyrethrum (65 galls./acre).

		Number of larvae.			
Date	Time of sampling beetle population.	Area treated with pyrethrum.	Control area.	Area treated with derris	Control area
17.8.38	Before spraying	76	93	34	44
17.8.38	At spraying	-	-	-	-
20.8.38	After spraying	33	40	57	34
21.8.38	" "	41	39	44	49

By comparing in Table XXVIII the number of larvae collected /

collected on treated, with that on untreated areas, three and four days after spraying, it is apparent that no control was effected.

In the experiments on the control of heather-beetles by means of insecticidal dusts, it was found that the application of 85 lbs. of derris or 65 lbs. of derris-pyrethrum mixture per acre in the spring was instrumental in reducing the population of beetles to about two-thirds and one-third of their original numbers respectively. The application of about half the above quantities was useless. On the other hand, the application in summer of 57 lbs. of derris or 26 lbs. of derris-pyrethrum mixture per acre was effective in destroying a large proportion of the larvae. Therefore it is more economical to apply insecticidal dusts against the larvae than against the adults. The use of wet sprays is not to be recommended since they were found to be less effective than dusts, and to involve greater labour.

The dusts were applied by means of a rotary dusting machine,+ (Plate III fig. 4) and the sprays by a knapsack sprayer. The best time to apply the dusts is the last week of July or early August when the larvae are on the heather in greatest numbers. A calm day should be chosen after rain and not /

+ The rotary dusting machine used in the experiments was one supplied by Messrs. Cooper Pegler & Co.

not when rain is threatening. Weight for weight, the derris-pyrethrum mixture has much better spreading properties than the derris dust alone and is thus more economical. In practice, it was found that quantities of less than 25 lbs. of derris-pyrethrum, or 50 lbs. of derris per acre could not be distributed uniformly. Exclusive of transport which varies considerably, the cost of dusting per acre is about 11s. with derris and 6s. with the derris-pyrethrum mixture.

Burning of heather.

Heather burning was advocated by Grimshaw (1913), Betrem (1929) and Cameron (1937) as a practical measure of controlling the heather-beetle. Whereas there was agreement that burning in July and August would destroy the larvae, diversity of opinion was expressed as to what effect the fire would have on the adult beetles and the time of year most suitable for the application of this measure.

Grimshaw considered that burning in winter would be of little use because the beetles are then dormant below the surface of the soil, and would thus escape destruction. It was suggested by Betrem that the beetles which have just awakened from their winter sleep in April might be destroyed by fire before they begin egg-laying. Cameron, on the other hand, recommended /

recommended burning in mid-winter when the vegetation was dry, so that it would burn quickly and produce heat of sufficient intensity to destroy the dormant beetles before they could burrow beyond its range or otherwise escape. Burning after the beetles have emerged from hibernation was considered as likely to fail in its purpose, since their natural reaction would be to resort to flight as soon as the rising temperature accompanying the fire reached them. In order to assess the value of heather burning in control, observations were made on the behaviour of the larvae and adults while a fire was in progress.

(a) Destruction of larvae.

Owing to the sluggish behaviour of the larva as compared with that of the adult, it was considered that their destruction could be achieved by burning infested heather in July or early August, but to confirm this, direct observation was necessary. In July 1939, a visit was paid to a Yorkshire moor where it is the practice to burn part of the heather then. For control of the heather-beetle, the last week of July is very suitable as the larvae are then in greatest abundance on the heather. Whilst the fire was in progress, observations on the behaviour of the larvae were made. As the smoke passed over the heather ahead of the fire, many of the larvae were observed to stop feeding /

feeding and to crawl slowly down the stems, but just as many were seen to continue feeding or to climb upward. Only a few dropped to the ground. Thus the behaviour of the larvae was far from uniform; while some appeared to exhibit signs of uneasiness, others showed no apparent symptoms of distress. When, however, the heat of the flames reached them, the majority dropped to the ground.

Immediately the fire had passed, an examination of the ground was made. No great difficulty was experienced in finding larvae by turning over and examining the burnt debris. Practically all had been destroyed by the flames. In fifteen minutes, 39 larvae were found of which 32 were dead and 7 alive. Of these latter, 4 were found on small patches which had escaped the flames.

It should be remarked that the fire was by no means intense or thorough, due to the sappy condition of the heather which, moreover, had been drenched by the heavy rain which fell just before the experiment was made. On the basis of this one experiment and despite unfavourable weather conditions, summer burning of heather would appear to be an effective method for controlling the larvae. Such larvae as might escape destruction would probably have difficulty in migrating to unburnt areas in order to obtain the food required for the completion of their life cycle. It is well to insist that burning should not be postponed /

postponed until the middle of August or later, because, by then, many of the larvae have pupated and are dormant below the surface of the ground.

(b) Behaviour of adults. Value of spring burning.

In Scotland, it is contrary to statute to burn heather in summer and it is, therefore, not possible then to employ this method of destroying the beetle grubs on their food plant. To determine the control value of burning in spring, observations were made on the behaviour of the adult beetles during the burning of infested areas in 1938 and 1939, and the following three examples illustrate the reaction of the beetles to the fire and the value of spring burning in control.

In April a visit was paid to a moor situated on the northern slopes of the Pentland Hills where the heather on the infested area to be burnt was short, patchy, and badly damaged. During burning there was a moderate breeze and the sun shone intermittently. The air temperature was 51°F. and beetles were active and abundant. As the smoke of the fire passed over the heather, many insects were observed to take to flight but heather-beetles were not seen on the wing. Three beetles were carefully watched. When the smoke reached them they became excited, scurried about on the heather, dropped to the ground, and finally burrowed /

burrowed beneath the surface. They made no attempt to escape by flying. As soon as the fire had passed, the ground was examined. Only the surface of the soil and moss were found to have been charred. Immediately beneath the layer of burnt matter, the ground was moist and cool. Many beetles were found without difficulty by lightly scraping away the burnt debris near the surface, but some had burrowed half an inch down. Of the beetles collected, thirty-three were alive and twelve dead. Of the latter, nine had obviously been dead for some time, so only three could have been injured by the fire or smoke.

On another occasion, in April on the Lammermuirs, a patch of rough old heather was burnt. There was a moderate breeze and continuous sunshine during the time of the fire, and beetles, with the temperature at 54°F., were very numerous and active. As soon as the smoke began to pass over the heather, the beetles dropped to the ground. This was shown by sweeping the heather with a net when not a single beetle was captured, whereas a few minutes before the smoke arose they had been caught in large numbers. Nor were beetles observed in flight. Beetles held in the hand, near the heat of the fire or in the smoke, ran about actively, tried to squeeze between the fingers, and eventually dropped to the ground; none attempted to escape by flying. Although the fire was very hot and fierce, only the surface of the ground was burnt; the ground just below the surface remained quite /

quite cool and moist. Two days after burning, the area was revisited and a search made for beetles. No living specimens were found, and of nineteen dead collected, only three could be said to have died recently. Thus it was apparent that the majority had escaped injury and dispersed to neighbouring unburnt tracts of heather.

On a third infested area on the northern slopes of the Pentland Hills damage was restricted to a small, well defined patch, about two acres in extent. The sloping ground round about was well drained. The area was burnt in April and the beetles dispersed. As the burning was done during a period of drought in spring, 1938, and the surrounding land was not suitable for the breeding of the beetles even in a normal season, they were practically eliminated from the locality.

That the reaction of the beetles to heather burning is not always the same is indicated by the following observations made by a correspondent in Wigtownshire who wrote: "The largest swarm I saw was on April 9th, 1936. I was heather burning; it was warm and sunny, not a puff of wind. The fire burned slow and well, and the beetles rose in front of it in such countless numbers that they darkened the air between me and the sun like a cloud, almost as dense as the smoke from the fire." What the reasons for this flight behaviour might have been is hard to say, but the ultimate result was the same, - protective.

It /

It appears that adult beetles are rarely destroyed by the fire during heather burning in spring. The smoke which precedes the flames, causes the beetles either to take to flight or to drop to the ground where, by burrowing beneath the surface, they escape injury by the fire. The approaching heat of the fire induces the same reaction as smoke. After the fire has passed, the beetles disperse over the neighbouring unburnt areas. Such dispersal is instrumental in retarding their increase, if the parts of the moor over which they spread are dry. It would seem also that burning in mid-winter would be equally ineffective since the heat of the fire does not penetrate to any depth, and the beetles which hibernate in the moss and soil would escape destruction. For the same reason, Betrem's (1929) assumption that the pupae would be destroyed by the heat of a fire in September must be discounted.

(c) The practice of heather burning.

It was found that moors where heather of 10 or more years predominated suffered more severely from attacks of heather-beetle than those where the heather was younger. Recovery by sprouting from the roots, if it occurs at all, is very slow indeed in old heather. The ideal system of moor management would thus appear to be one in which at least one tenth of a moor is burnt each year. This ensures the maintenance of a continuous supply of young heather which, in the event of beetle attack, is capable of /

of quicker recovery from damage than older heather (Plate IV, fig.2

The practice of burning heather in short rotation is one that is essential to any scheme of efficient moor hygiene (Anon. 1938). The opinion has frequently been expressed by gamekeepers and moor-owners that old heather is necessary to provide requisite cover for grouse, but the proportion of such heather that should be left for this purpose is a matter about which there is some dispute. Lord Lovat (1911) made the statement that "at least 75 per cent of the larger moors examined are insufficiently burned." This is equally true today. Even where moor owners are convinced of the advantage of short rotational burning, difficulties exist which prevent its effective practice. Shortage of labour, lack of time and inclement weather may hamper the accomplishment of spring burning of heather within the allotted time. Again there is the question of the general condition of many moors where there are extensive tracts which are seldom dry enough to burn thoroughly To ensure that such tracts will not form foci of beetle infestation, it is highly desirable that they should be first drained and then submitted to the rotational system of burning like the rest of the moor.

Examination of moors in all parts of the country has shown that those that are well drained and submitted to a ten years' rotational system of burning are not seriously affected by heather-beetle /

heather-beetle attacks. Even if an attack should occur, it is likely to be slight and of short duration, and recovery is more certain and rapid than on neglected moors.

Drainage of moorland.

That the egg stage is the most critical period in the life history of the heather-beetle has been satisfactorily demonstrated. For successful development the eggs require a humid environment. Although slow in exerting its ameliorating effect, drainage of boggy moorland is undoubtedly the method which is most calculated to obviate or restrict periodic increases of this pest. This was recognised by Grimshaw (1913) and stressed by Cameron (1937). It is well to bear in mind too, that drainage also encourages the growth of healthy heather (Anon. 1938).

Recently on a Perthshire moor, an extensive scheme of drainage involving 5,000 acres was completed at a cost of £325, i.e. 1s. 4d. per acre. In all, 6,000 chains of drains, 17 inches deep, were cut at varying distances of 15 to 30 yards apart according to the nature and contour of the hill (Plate IV, fig. 1). The cost per chain was 1s. 1d. As a result of the drainage, the general hygiene condition of the moor has been much improved. Although the cost of drainage is high, the results are such as to warrant the adoption of the practice more widely on moors susceptible to heather-beetle attack.

OTHER INSECTS INJURIOUS TO HEATHER.

Strophosomus lateralis, the heather-weevil.

The heather-weevil, S. lateralis (Plate II, fig. 1) is smaller and less active than the heather-beetle, L. suturalis, but like the latter, the adults feed on the leaves and shoots of ling heather. Though not so universal in its distribution as L. suturalis, it has been found locally in large numbers. It is of interest because the larvae have frequently been mistaken for those of the heather-beetle by gamekeepers and others who may disturb them in the soil when uprooting young injured heather. The larvae (Plate II, fig. 2) of S. lateralis feed on the roots of heather and not on the leaves and shoots as do the larvae of L. suturalis and, like all weevil larvae, they are white, legless, and somewhat curved.

The weevil was described briefly by Cameron (1937) and little further information has been obtained concerning its habits. The roots of very young heather were found only occasionally to have been severely injured by the larvae. Where damage to heather over large areas of moorland was attributed to the "grub" at the roots, investigation usually showed that the real cause of injury was the larva of L. suturalis feeding on the leaves and stems of the plants. The adults were found on heather at all seasons of the year. Eggs were not discovered in the field, nor did captive weevils oviposit in the laboratory. Several specimens, however, which /

which were dissected in June, 1938, were found to have mature ovaries. Larvae and pupae were recovered from soil samples examined during the months November, 1937, to March, 1938, and in June and September, 1938. All stages in the life history, therefore, except the eggs, were found during each season. By far the largest number of adults collected, however, at one time was captured on a Lanarkshire moor in mid-September, 1937 (Table I).

Orgyia antiqua, The Vapourer moth.

Although it is difficult to imagine any degree of resemblance between the various stages of the Vapourer moth and those of the heather-beetle, nor any similarity between the appearance of the heather damaged by the two insects, yet the work of the Vapourer caterpillars is occasionally confused by the layman with that of the beetle. In the male moth the wings are brown and measure 1 to $1\frac{1}{2}$ ins. across, and in the female they are mere vestiges. The caterpillars are brightly coloured with red, yellow and blue lines and dots; and they possess conspicuous tufts of long "hair". They feed on the leaves of heather in summer and are about $1\frac{1}{4}$ ins. long when full-grown. In autumn, the female moths remain clinging to, and oviposit on the cocoons which are usually attached to the food plant. The eggs hatch in spring. In general, the damage done by the caterpillars is confined to an area of less than half an acre, roughly circular in outline, and each year it spreads but slowly from an infested centre since the female is unable to fly.

Control /

Control of the moth is easily procured by burning at any time of the year a patch of heather slightly greater than that infested by the caterpillars.

INJURIES TO HEATHER FROM CAUSES OTHER THAN INSECT PESTS.

Unhealthy heather usually turns fox-red and, in the past, a great deal of injury to heather has been attributed to the action of frost which has in reality been due to the activities of the heather-beetle. Cameron (1937) described the change of colour undergone by healthy heather in winter from green to purplish-brown. This alteration appears to be related to internal physiological changes associated with exposure to cold weather and to be such as to render the plant less susceptible to the effect of low temperatures. With the return of spring, fresh shoots appear and the plant becomes green once again. It may well be that even mild frost in spring can injure growing heather, but experiments by Braid and Tervet (1937) showed that tender young shoots are very hardy and can withstand a day's exposure to 26°F. followed immediately by exposure to bright sunlight at 90°F. for four hours.

In one locality in Perthshire, an unusual form of damage was noticed on a small exposed area of very old heather. The stems which were dark red had been defoliated and were partially stripped /

stripped of their bark, but no sign of insect or fungous attack could be recognised. It is quite possible that the damaged condition of the plants was due to the friction of the leafless stems on each other caused by wind pressure.

Soil poverty was apparently responsible for unsatisfactory growth of the heather on a Stirlingshire moor where new growth in spring was reported to be very slight; the plants remained hard and sapless. On examination, the ground was found to be very broken, and the affected heather was present on the higher and drier portions of the moor, on rocky mounds where the soil was very shallow. As was to be expected, there was no trace of heather-beetle activity on such ground. Transverse sections of the plant stems showed a series of 10 or 11 annual rings of growth. During the first 7 years, growth, as judged by the broad inner rings, had been regular and uniform whilst the narrowness of the outer rings indicated that the annual increment in the last three or four years had been very slight. The soil conditions were judged to be so poor as to have limited the normal growth of the heather and a rotational system of burning of not more than 7 years would have been advisable.

As to whether there are fungi which are primary parasites of healthy heather is not known with certainty. Betrem (1929) recorded a species of _Corticium_ on both ling, _C. vulgaris_, and bell heather, _Erica sp_., in Holland. Braid and Tervet (1937) have /

have reported the widespread occurrence in Scotland of a Rhizomorph fungus on dying and dead heather, but consider it a weak secondary parasite which attacks only heather that is unhealthy because of beetle activity or some other cause.

Frequently individual plants of very young heather have been found wholly or partially fox-red but without signs of insect or fungus attack. It was considered possible that this might be due to the scorching effect of solid or liquid excreta of sheep or rabbits, but the evidence is purely circumstantial, namely, the finding of dung around many affected plants. Affected plants generally recover after a few weeks, especially where there is frequent rainfall.

Overstocking with sheep is not related to the subject of the investigation, but it is well to point out that, where small patches of heather have been burned in the ordinary process of moor management, growth may be definitely retarded by the effects of overgrazing with sheep.

SUMMARY.

Outbreaks of the heather-beetle L. suturalis have been recorded periodically since 1853.

There is only one generation of the beetle per annum, and there is no obligatory diapause in the life cycle. The activites of /

of the beetle are mainly confined to boggy moorlands. The eggs require a humid environment for their successful development, and are chiefly laid on sphagnum moss.

Natural enemies were not found to exert any significant degree of control of the beetle. A tachinid parasite, Degeeria collaris, was recorded from one locality only. Its most important enemy was found to be the predatory ladybird beetle, Coccinella hieroglyphica.

Rainfall in spring and early summer during the breeding season of the heather-beetle is believed to be the principal factor which determines its rate of multiplication. Abnormally low precipitation during these seasons is considered to be responsible for checking the activities of the beetle.

Insecticidal dusts applied to infested heather in summer serve to control the larvae of the beetle, but are ineffective against the adults in spring. A mixture of derris and pyrethrum is cheaper than derris alone and is equally effective.

Muir burning in July and August controls the larvae of the beetle, but not the adults when carried out in spring. Heather burning has the advantage that it encourages the growth of young heather which recovers more quickly from heather-beetle attack than does older heather. A ten years' rotational system of burning is therefore recommended.

Drainage /

Drainage is considered the most satisfactory and permanent method of controlling the destructive activities of the heather-beetle. Drainage removes excess moisture, discourages the growth of sphagnum and thereby renders the environment of the beetle less suitable for breeding. Moreover, drainage permits of more frequent heather burning so that the proportion of young heather throughout a moor may be increased.

Among insects other than the heather-beetle that are occasionally injurious to heather, the heather-weevil and the Vapourer moth are the most important. Heather too, may suffer injury from causes other than insect pests.

REFERENCES.

Anon. (1938). The Stock-carrying Capacity of Hill Grazings in Scotland. Scot. Jour. Agr. XXI, 226-7.

Betrem, J.G. (1929). De Heidekever en Zijn Biologie. Tijdschr. Plantenzieht., XXXV, 150-80.

Braid, K.W. and Tervet, I.W. (1937). Certain botanical aspects of the dying-out of heather. Scot. J. Agr., XX, 365-372.

Cameron, A.E. (1937). The Heather-Beetle (Lochmaea suturalis). Trans. High. Agr. Soc. Scot., XLIX, 111-28.

-------------- (1937). The Heather-Weevil (Strophosomus lateralis). Trans. High. Agr. Soc. Scot., XLIX, 128-9.

Carpenter, J.R. and Ford, J. (1936). The use of sweep net samples in an Ecological Survey. Jour. Soc. Brit. Ent. I, 155-161.

Corax. (1930). Die Wahrheit vom Heidesterben. Mitt. Deutsch. Dendrol. Gesellsch. XLII, 379.

Cornelius, C. (1858). Entomologische Notizen. 2. Adimonia capreae. Entom. Zeitung Stettin., XIX, 221.

------------- (1862). Entomologische Notizen. 2. Adimonia capreae. Entom. Zeitung Stettin., XXIII, 272.

Cousin, G. (1932). Etude Experimentale de la Diapause des Insectes. Bull. Biol. Fr. et Belg., XV, Suppl., 1-341.

Fowler, C. (1891). Lochmaea suturalis. Coleoptera of the British Islands. London., IV, 326.

Grimshaw, P.H. (1898). The Heather-Beetle. Ann. Scot. Nat. Hist. 27-9.

------------- (1911). The Heather-Beetle. The Grouse in Health and Disease. London. I, 414-29.

------------- (1913). The Heather-Beetle. The Field. London. July.

Laidlaw, W.B. (1937). Aphidecta obliterata Linn. (Coccinellidae) Its efficiency as a control factor of Adelges cooleyi. Gillette. Scot. For. Jour. LI, 143-67.

Lovat, /

Lovat, Lord. (1911). Heather Burning. The Grouse in Health and Disease. London. I, 392-413.

Metzger, F.W. (1928). Information concerning Japanese Beetle Traps. Dept. Agr. N.J. U.S.A. Circular 146.

Morison, G.D. (1938). The Heather-Beetle (Lochmaea suturalis Thos.) Aberdeen Journals Ltd. Feb.

Parker, E. (1936). Menace of the Heather-Beetle. The Field. London. 552-3.

Prell, H. (1929). Beitrage zür Kenntnis der Morphologie und Biologie der einheimischen Lochmaea Arten. Entom. Blätter. XXV, 1-11.

Thomas, B. (1937). The composition and feeding value of heather at different periods of the year. Jour. Min. Agr. XLIII, 1050-55.

Thompson, C.G. (1866). Lochmaea suturalis. Scandinaviens. Coleoptera. III, 151.

Thompson, W.R. (1920). Sur un nouveau Parasite de la Galeruque de l'Orme. Degeeria collaris Fall. (Diptera Tachinidae). Bull. Soc. Entom. France. X, 180-4.

Uvarov, B.P. (1928). Locusts and Grasshoppers. London. 62-3.

Weise, J. (1893). Coleoptera (Chrysomelidae). Naturgeschichte der Insekten Deutschlands. VI, 613-5, 1132.

Explanation of Plates I to IV.

Plate I. Life History stages of L. suturalis. Fig. 1, Adult, x 9. Fig. 2, Pupa, x 9. Fig. 3, Larva, x 8. Fig. 4, Eggs on sphagnum moss, x 8.

Plate II. Fig. 1, Adult of S. lateralis, x 15. Fig. 2, Larva of S. lateralis, x 15. Fig. 3, Adult of C. hieroglyphica, typical form, x 22. Fig. 4, Larva of C. hieroglyphica feeding on larva of L. suturalis, x 6.

Plate III /

Plate III. Fig. 1, Old heather killed by _L. suturalis_. Fig. 2, Sprig of heather damaged by larvae of _L. suturalis_ and an undamaged sprig for comparison. Fig. 3, sphagnum moss, _S. acutifolium_, desiccated and bleached during the spring drought, 1939. Fig. 4, Dusting heather with a Rotary dusting machine.

Plate IV. Fig. 1, Example of a surface drain such as is cut on swampy moors to reduce the moisture content. Fig. 2, Young heather which replaced a stand of 8-year old heather one year after burning.

Plate I.

Figure 1.

Figure 2.

Figure 3.

Figure 4.

Plate II.

Figure 1.

Figure 2.

Figure 3.

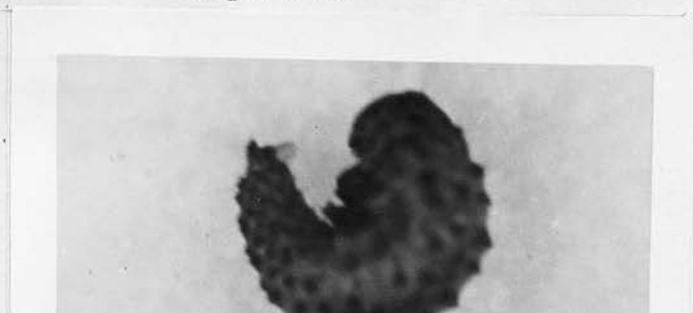


Figure 4.

Plate III.

Figure 1.

Figure 2.

Figure 3.

Figure 4.

Plate IV.

Figure 1.

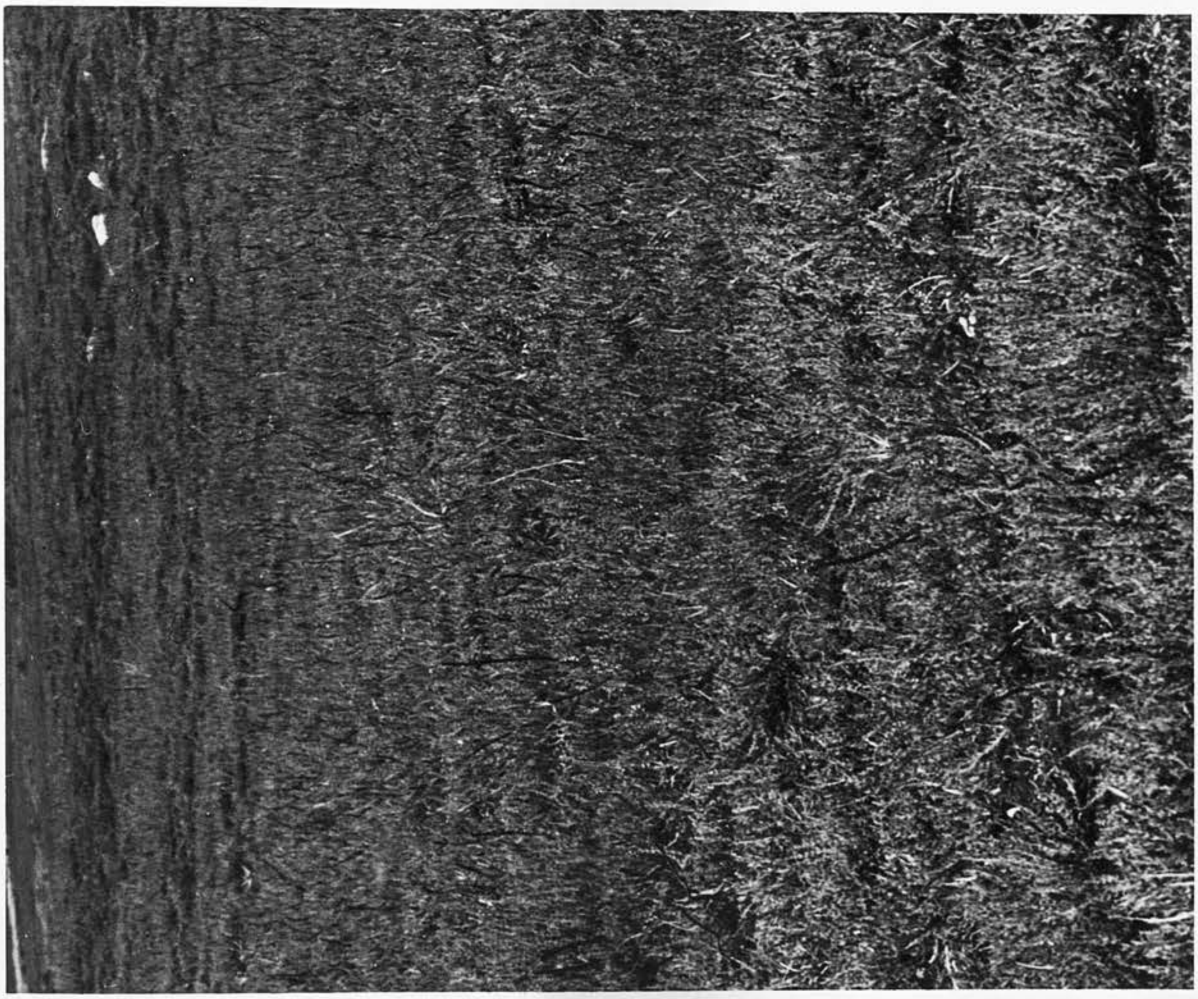


Figure 2.